MARINE GAS AND DIESEL ENGINES

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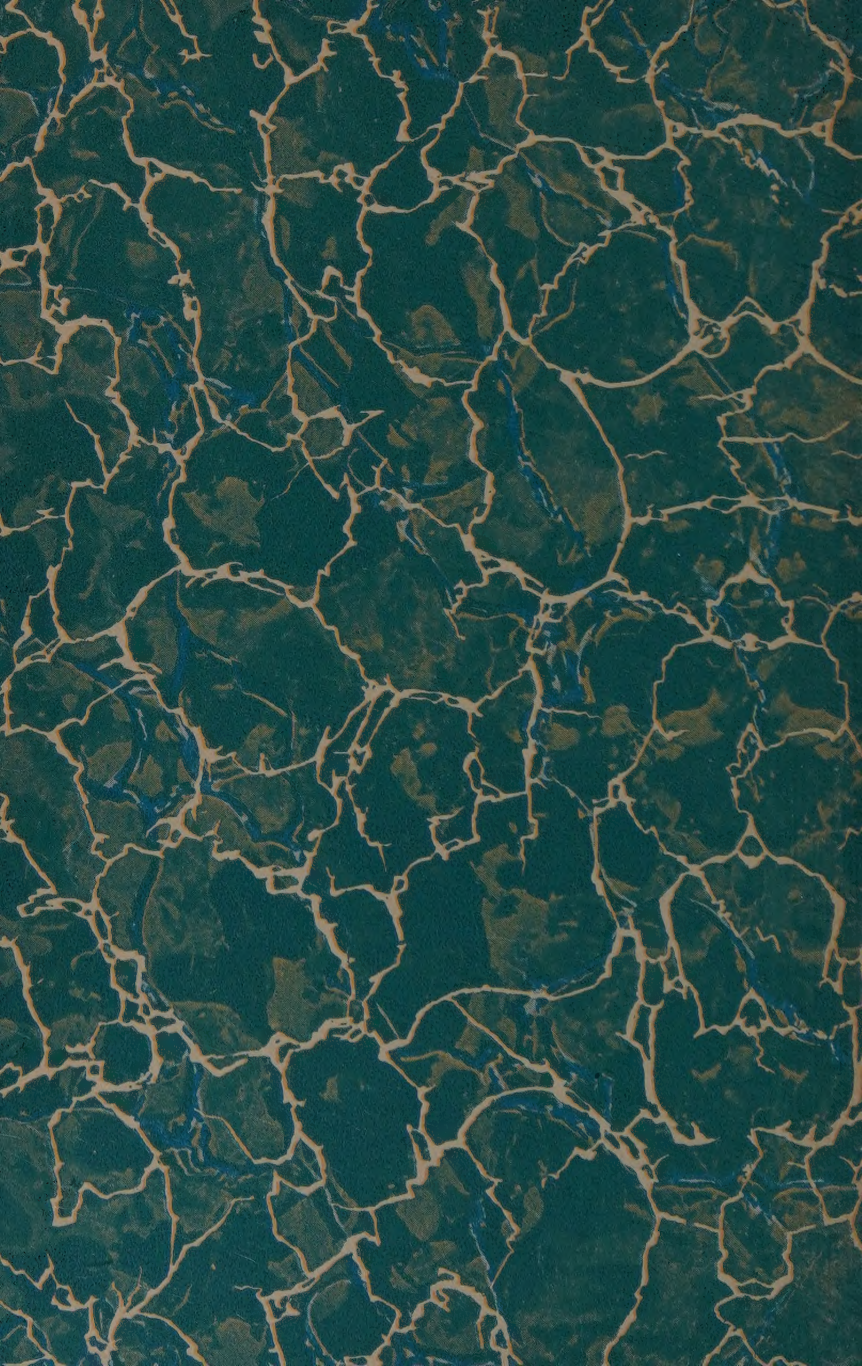

Marine Gas and Diesel Engines

By
L. V. GOEBBELS

MARINE GAS ENGINES
MARINE DIESEL ENGINES
MANAGEMENT OF MARINE GAS ENGINES

352

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MARINE GAS ENGINES

Serial 2044 Edition 1

TYPICAL MARINE ENGINES

TWO- AND FOUR-CYCLE TYPES

INTRODUCTION

1. Internal-combustion engines for use in marine service embody the same principles as those used in stationary work; that is, they are of the two-cycle and four-cycle types. Their action, therefore, is like that of other two-cycle and four-cycle engines. In construction they are similar to stationary and automobile types, but the marine engine as a rule is considerably lighter than the stationary engine of equal power. The smaller engines are usually built to use gasoline or kerosene as fuel, but there are some small engines that can be run on gasoline, kerosene, gas oil, or fuel oil. The larger engines, particularly those intended for lake and sea-going vessels, are designed to use fuel oil, distillate, solar oil, and the heavier crude oils. Although the nature of the fuel has such a wide range, the term marine gasoline engines will be used in this Section to designate all forms of internal-combustion engines for service on fresh or salt water.

2. Practically all marine gasoline engines are of the vertical type. Obviously, this arrangement of the cylinders is preferred for marine engines because headroom is more avail-

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able than floor space, and a vertical engine will cover a smaller area than a horizontal engine of equal power. The marine engine is set with its crank-shaft lengthwise of the vessel, or fore-and-aft, and is usually connected with the propeller shaft through some form of transmission gearing by which the direction of rotation of the propeller may readily be reversed. This gearing also includes a clutch, by which the propeller shaft may be engaged with the engine shaft or disengaged from it. In the case of some of the smaller two-cycle engines, no reversing gear is used and the engine shaft is connected with the propeller shaft through a clutch alone. The reversing of the propeller is then accomplished by running the engine backwards.

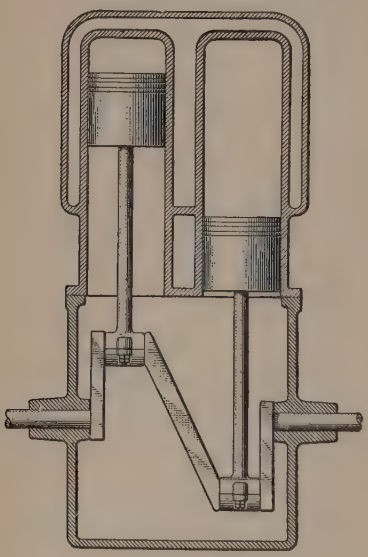


FIG. 1

3. As a general thing, two-cycle gasoline engines are used on the smaller class of motor boats, such as runabouts on lakes and rivers and small dories on deep water. These engines are usually built with one, two, or three cylinders and develop from 3 to 25 horsepower, although some two-cycle engines are made with four and six cylinders and develop as high as 48 horsepower, or more. However, engines of four cylinders or more are usually of the four-cycle type. Engines having but one or two cylinders are rarely of the four-cycle type because, for the same number of cylinders, two-cycle engines give twice as many power impulses per revolution and consequently run more smoothly. In addition to this, the first cost of small two-cycle engines is less than that of four-cycle motors, and they are usually of simpler construction. Two-cycle motors will run in either direction, and a large number

of these engines are designed so that they may easily be reversed, thus obviating the use of a reversing gear in the propeller shaft.

ARRANGEMENT OF TWO-CYCLE ENGINE CRANKS

4. A two-cylinder two-cycle marine engine usually has its cylinders arranged side by side, as in Fig. 1, and the cranks at an angle of 180° apart, or directly opposite each other. In other words, while one piston is moving downwards on its impulse stroke, the other is moving upwards on its compression

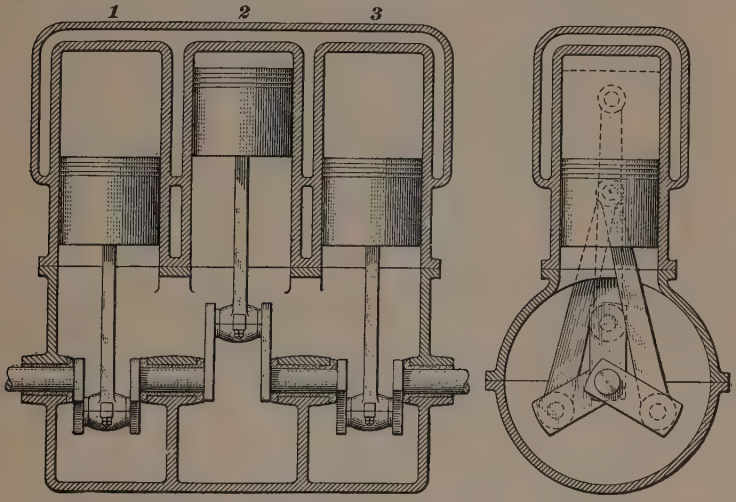


FIG. 2

stroke, so that the explosions alternate, occurring first in one cylinder and then in the other. By this arrangement, an impulse occurs every half revolution and the moving parts are well balanced.

5. Three-cylinder two-cycle engines are generally arranged as shown in Fig. 2. The cranks are 120° apart, that is, they are arranged at equal distances around the crank-shaft, so that the impulses occur every third of a revolution. With this arrangement and starting with the first cylinder, an explosion occurs first in cylinder *1*, then in cylinder *3*, and lastly in

cylinder *2*; or in other words, the order of firing in such an engine is *1–3–2*.

6. In the four-cylinder two-cycle engine, all the cylinders are generally arranged in line on one side of the crank-shaft, as shown in Fig. 3. The cranks are arranged 90° apart, hence four impulses occur at equal time intervals for each revolution of the crank-shaft. In order to balance each other and thus

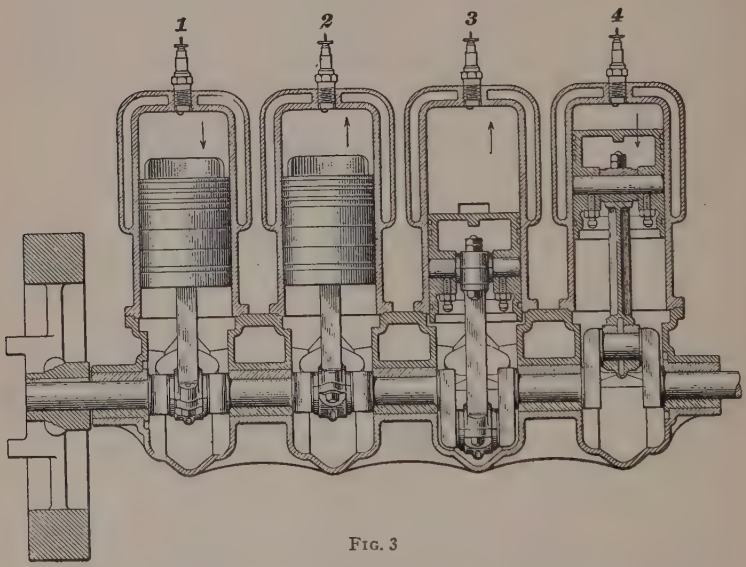


FIG. 3

prevent any great vibration, the cranks are arranged so that cranks *1* and *2* are directly opposite each other and *3* and *4* are directly opposite each other, as shown. Beginning with cylinder *1*, an explosion occurs first in that cylinder, then in cylinder *4*, then in *2*, and finally in *3*; or, in other words, the firing order is *1–4–2–3*. The arrows show the directions in which the pistons are moving, and the numbers at the top indicate the usual numbering of the cylinders, *1* being at the front end of the engine and *4* at the rear, or bulkhead, end.

TYPICAL TWO-CYCLE ENGINES

7. Single-Cylinder Two-Port Engine.—A single-cylinder two-cycle engine of the two-port type is illustrated in Figs. 4 and 5. Fig. 4 is an external view of the engine, and Fig. 5 is a longitudinal section through the center, showing the internal construction. The same parts are marked with the same reference letters in the two illustrations.

8. Fig. 4 shows the inlet side of the engine, with the carbureter *a* for mixing gasoline vapor and air in the proper pro-

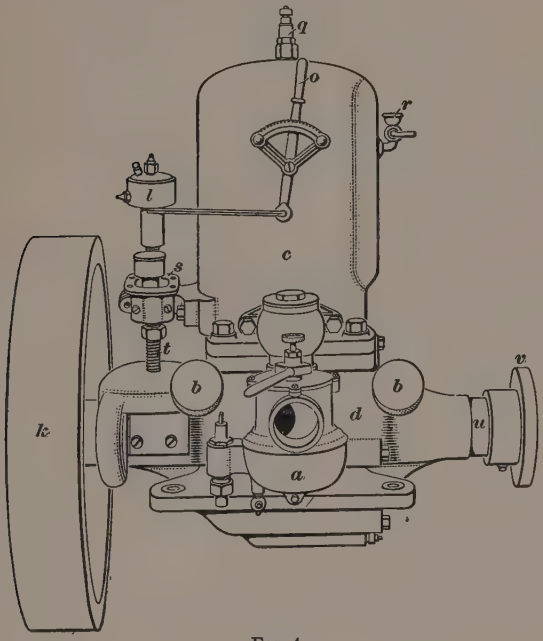


FIG. 4

portions, and the main-bearing oil cups *b*. These parts are not shown in Fig. 5, because there the front half of the cylinder *c* and crank-case *d* are removed. The exhaust gases pass out of a port located on the opposite side of the cylinder. The piston *e* is connected to the crank-shaft *f* by means of the connecting-rod *g* and crank *h*, the crank being provided with

counterweights *i* for balancing the engine. The crank-shaft, which turns in the main bearings *j*, is provided with a heavy flywheel *k* that stores up energy during the impulse stroke and thus carries the engine over the compression stroke. By means of the timer, or commutator *l*, the time at which the explosion takes place in the cylinder is varied. The timer is

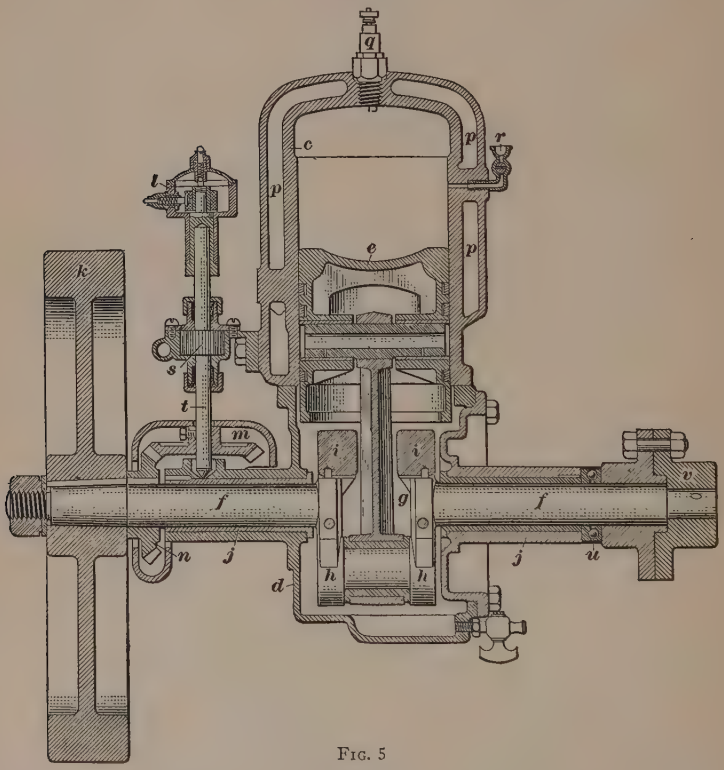


FIG. 5

driven from the crank-shaft by the bevel gears *m* and *n*, and the timing is varied by moving the lever *o*, Fig. 4.

9. The cylinder proper is surrounded by a jacket *p*, Fig. 5, through which water is circulated for the purpose of keeping the cylinder walls cool. The combustible mixture is ignited by means of a spark plug *q*, while the priming cup *r* is used for pouring in gasoline, or *priming the cylinder*, in order to start

readily. The pump *s*, by means of which the water is forced through the jacket space, is rotated by the timer shaft *t*. The thrust bearing *u* prevents the coupling *v* from being forced endwise by the thrust, or endwise pressure, exerted by the propeller in driving the boat.

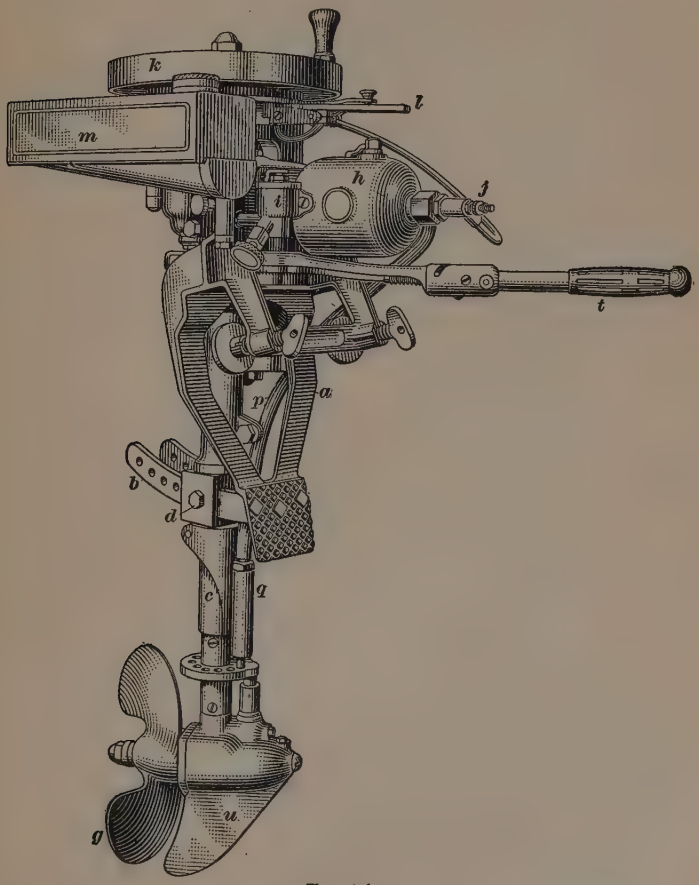


FIG. 6 (*a*)

10. The single-cylinder two-cycle engine shown in Fig. 6 (*a*) and (*b*) is of the outboard type, so called because it is designed to be attached to small craft outboard, or on the outside, instead of being installed in the boat. For this reason

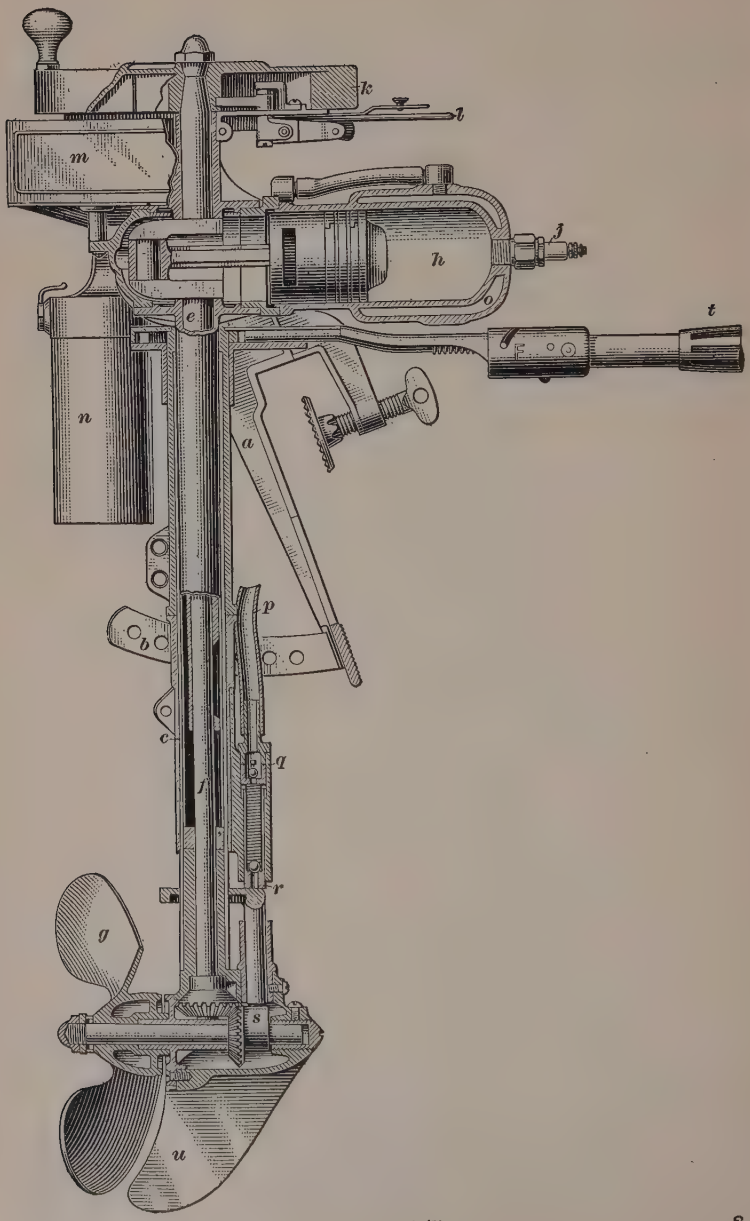


FIG. 6 (*b*)

the engine, crank-shaft, propeller shaft, propeller and rudder are all carried by a frame that is pivoted to the bracket *a* by which the motor is fastened to the stern or side of the boat. The bracket has a quadrant *b* along which the propeller sleeve *c* may be swung and to which it may be locked in the desired position by the screw *d*. This enables the direction of the propeller shaft to be altered to suit the angle of the stern of the boat. The propeller sleeve *c* is made with a telescope joint and the length of the coupling between the crank-shaft *e* and the shaft *f* may be varied, so that the depth of the propeller *g* below the surface of the water may be altered as desired.

11. The engine cylinder *h*, Fig. 6, is at right angles to the crank-shaft, which is approximately vertical. The action of the engine is like that of the usual two-cycle type. The explosive mixture is drawn into the crank-case by the suction of air through the mixer *i*, compressed in the crank-case, and carried to the combustion chamber through suitable ports. It is ignited by a spark between the terminals of the spark plug *j*, the high-tension current being supplied from a magneto built into the flywheel *k*. The speed of the engine is controlled by the lateral movement of the timer lever *l*, which is within easy reach of the operator. The internal lubrication of the engine is effected by the admission of lubricating oil with the fuel, the two being mixed in correct proportions in the fuel tank *m* when it is filled.

12. The exhaust gases from the engine in Fig. 6 are conveyed by a water-jacketed exhaust pipe to the muffler *n*, from which they are discharged downwards. The water surrounding the exhaust pipe comes from the water-jacket *o* of the cylinder, to which it is supplied through a flexible hose *p* by the pump *q*. This pump consists of a reciprocating plunger *r* that is forced upwards against the resistance of a helical spring inside by the action of a cam *s* on the hub of one of the miter gears by which the propeller is driven. The plunger is hollow and contains a ball valve that opens on the downward, or suction, stroke only. Above the plunger is a similar ball valve

that opens only on the upward, or discharge, stroke. The steering is done by means of the handle *t*, which is swung to right or left, causing the propeller sleeve to turn with it and thus swinging the rudder *u* and the propeller *g*.

13. Single-Cylinder Three-Port Engine.—The three-port two-cycle engine differs from the two-port engine by having the inlet port for the fuel open into the cylinder bore at a point above the crank-case, in which position it is opened and closed by the movement of the piston over it, whereas in the two-port type it opens directly into the crank-case or the transfer port. The three-port engine needs

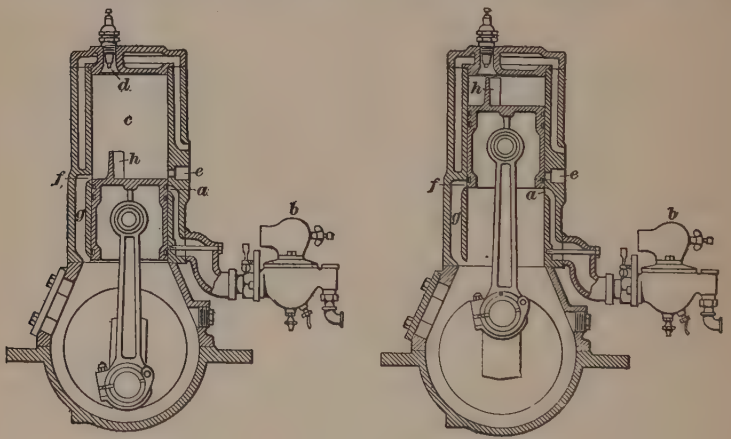


FIG. 7

no valves, since the piston acts in the place of valves, and so this type is sometimes called the valveless two-cycle engine. Two sectional views of the cylinder of a three-port engine, showing the piston at the bottom and the top of its stroke, respectively, are given in Fig. 7 (*a*) and (*b*). As the piston moves upward from the position shown in view (*a*), the volume of the crank-case increases, and as the crank-case is air-tight, the pressure inside it is reduced. In other words, a partial vacuum is formed in the crank-case. As the piston nears the top of its stroke, its lower edge uncovers the port *a* that leads to the carbureter *b*, and air is drawn through the

carbureter, where it mixes with the gasoline vapor, with the result that the crank-case is filled with an explosive mixture of air and fuel vapor.

14. On the upper side of the piston, during the upward stroke, the volume of the cylinder space *c*, Fig. 7 (*a*), is reduced; that is, the explosive mixture of air and gas in the cylinder is being compressed. At just about the end of the stroke, or when the piston has reached the position shown in view (*b*), a spark at the spark plug *d* ignites the compressed charge and the resulting expansion of the gases drives the piston downwards on its working stroke. As it descends, it passes over the inlet port *a*, and no more air or fuel can enter. The mixture that already has entered the crank-case is compressed somewhat by the descending piston, and so is under a slight pressure by the time the piston reaches the bottom of its stroke.

15. Just before the piston reaches the bottom of its stroke, it uncovers the exhaust port *e*, Fig. 7 (*a*), and the burnt gases in the cylinder escape to the exhaust pipe. Very soon after it begins to uncover the exhaust port *e* it also begins to uncover the port *f* at the opposite side of the cylinder, which communicates with the crank-case by way of the transfer port *g*. By the time the piston reaches the bottom of the stroke, both ports *e* and *f* are wide open. As the mixture in the crank-case is under pressure, due to compression by the downward stroke of the piston, it flows up through the passage *g* and escapes into the cylinder through the port *f*, where it strikes the deflector *h* on the piston and is thrown upwards. The incoming explosive charge thus flows into the top of the cylinder and helps to drive out the exhaust gases through the port *e* below. This action is called scavenging, and assists in clearing the cylinder of burnt gases.

16. In spite of the fact that the ports *e* and *f*, Fig. 7, are open at the same time, no fuel is wasted. The greater part of the burnt gases escapes before the port *f* is uncovered by the piston, and the deflector *h* prevents the incoming charge from flowing directly across the piston to the exhaust port. More-

over, these ports are open only a fraction of a second, because the piston immediately starts on its next upward stroke and it has to move only a small distance to close both the port *f* and the exhaust port *e*. After these ports are covered by the pis-

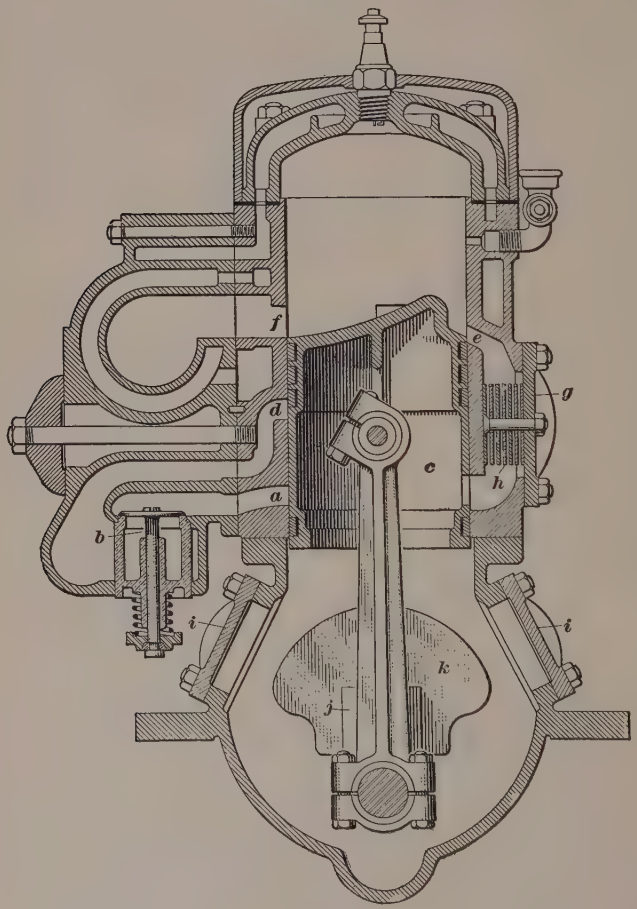


FIG. 8

ton, the charge in the space *c* is compressed by the upward movement of the piston and is exploded when the piston reaches the position in view (*b*). At the same time, a fresh charge is admitted to the crank-case through the uncovered

port *a*. This cycle of events is repeated as the engine continues to run.

17. Combination Two- and Three-Port Engine.—A cross-sectional view of a combination two- and three-port engine of the two-cycle type is shown in Fig. 8. A crank-case inlet port *a* is controlled by a valve *b*, such as is provided in the regular two-port type of engine, and an inlet port controlled only by the up-and-down movement of the piston *c*, such as is employed in the three-port type, is located at *d*. Port *a* is known as the **second port** and *d* as the **third port.** At *e* is shown the transfer port by means of which the charge travels from the crank-case to the combustion chamber when the piston is in the position shown. The exhaust port *f* is opened in the usual manner by the piston on its downward stroke.

18. The valve *b*, Fig. 8, that controls the second port *a* allows the combustible mixture to enter the crank-case when this port is opened on the upward stroke of the piston, but it prevents the charge from flowing back into the intake pipe and carbureter when the piston descends. The port *d* is placed so high up in the cylinder wall that the piston covers it as soon as the downward stroke is begun, and thus prevents the gas from escaping by that passage. The by-pass plate *g* carries a device *h* that prevents the burning gases in the combustion chamber from burning back into the crank-case on the impulse stroke. Such a burning back of the gases would cause an explosion of the gases in the crank-case, which would be extremely undesirable. The interior of the crank-case may be reached by removing the handhole covers *i*. The crank *j* is provided with counterweights *k* for the purpose of balancing the engine and causing smooth running.

19. The advantage claimed for the combination two- and three-port engine is that when running at slow speeds the second port insures reliability and an economical fuel mixture, while at high speeds the third port makes possible the development of the most power obtainable. It is usually true that at

low speeds a two-port engine will develop greater power than a three-port engine but that the latter will develop a little more power at high speeds; hence, it has been thought that, by combining the two, the most economical conditions at both high and low speeds might be obtained.

20. Two-Cylinder Two-Cycle Engines.—Marine gasoline engines having two or more cylinders operate on exactly the same principle as single-cylinder engines. Each cylinder has its own cycle of operations, which are usually timed so that the explosions in the different cylinders will occur at regular intervals. Usually one carbureter supplies the fuel to all the cylinders, although some two-cycle engines having three or more cylinders have a separate carbureter for each cylinder in order to insure a full charge.

Two-cylinder engines may have their cylinders cast separately or in pairs. When cast separately, either cylinder may be unbolted and removed from the crank-case independently of the other; but when cast in pairs they form one piece. When all of the cylinders of an engine are made in one casting they are said to be cast *in block*, or *en bloc*.

21. A two-cylinder two-cycle marine engine with its cylinders cast separately is shown in Fig. 9, in which (*a*) is an external view and (*b*) is a cross-section. This engine is of the three-port type but in construction it is very similar to the single-cylinder, two-port engine previously described. One carbureter *a* supplies fuel to both cylinders. To help vaporize the fuel, hot air is carried by the pipe *b* from a heater about the exhaust pipe *c* to the carbureter. Each cylinder is provided with a water pump *d*, which is of the plunger type and is operated by an eccentric *e* on the crank-shaft; the same eccentric operates an igniter *f* on each cylinder. This igniter creates a spark inside the combustion chamber, thus igniting the charge at the proper time. A centrifugal oil ring *g*, view (*b*), conducts lubricating oil through a duct *h* to the crank-pin. A screen *i* in the transfer port prevents a flame from passing back into the crank-case and causing an explosion. The cylinder heads *j* and the handhole plates *k* are bolted on; they are

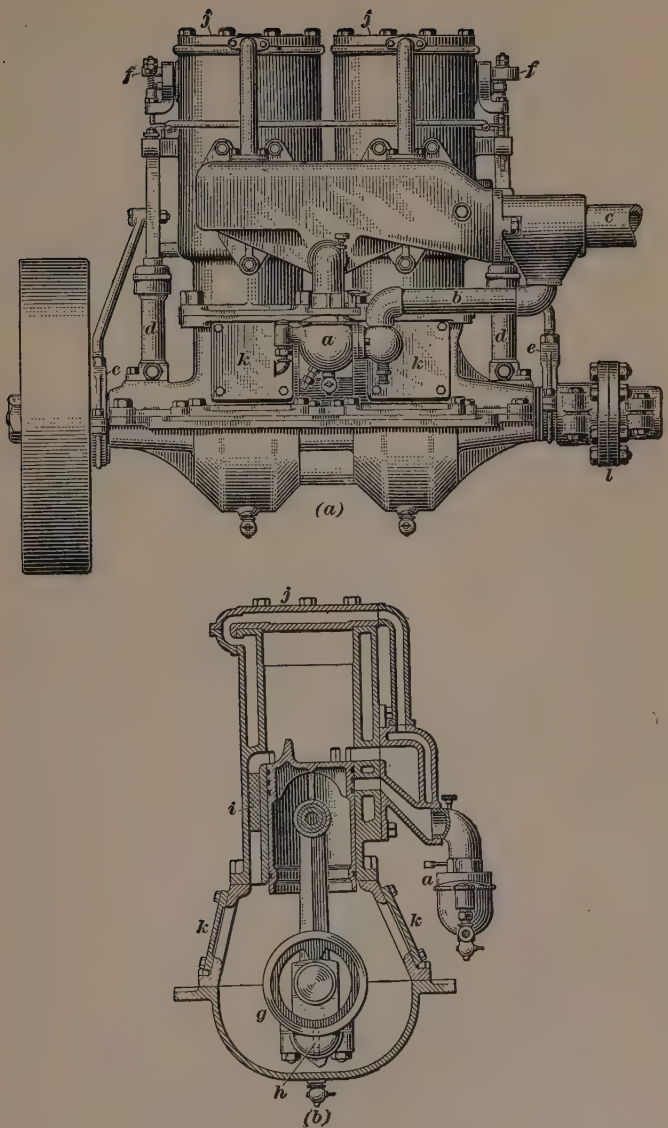


FIG. 9

therefore removable, providing ready access to the interior of the cylinders.

22. In Fig. 10 is shown an external view of a two-cylinder two-cycle engine with the cylinders cast in one piece, or in block. A water-jacket surrounds both cylinders, water being forced through it by means of the plunger pump *a*. Each cylinder is provided with a spark plug *b*; the time at which the spark will occur is varied, or controlled by the lever *c* that operates a timer *d* on the crank-shaft. The carbureter *e* sup-

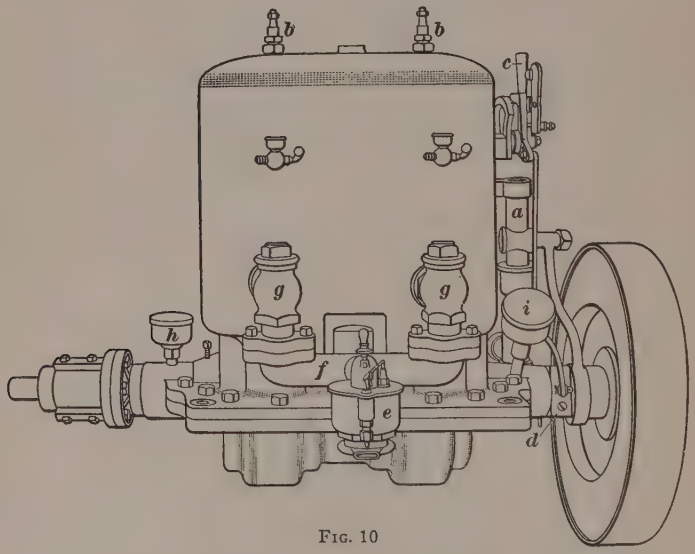


Fig. 10

plies fuel to both cylinders through the intake manifold *f* and intake pipes *g*. The oil cups *h* and *i* supply oil to the crank-shaft bearings. This style of engine has a very compact appearance and the advantage claimed for it is that the block casting insures absolute alinement of all parts at all times.

23. The two-cycle engine shown in Fig. 11 is of the two-cylinder opposed type and forms part of a rowboat motor, or outboard motor. The two cylinders *a* and *b* are directly in line, on opposite sides of the crank-shaft, and as the explosions occur at the same moment in both cylinders there is practically

a neutralizing of the shock, with the result that no rocking or vibration is communicated to the boat. The crank-shaft is geared to the propeller *c* in the usual way and steering is done by a rudder *d* through the medium of the steering handle *e*.

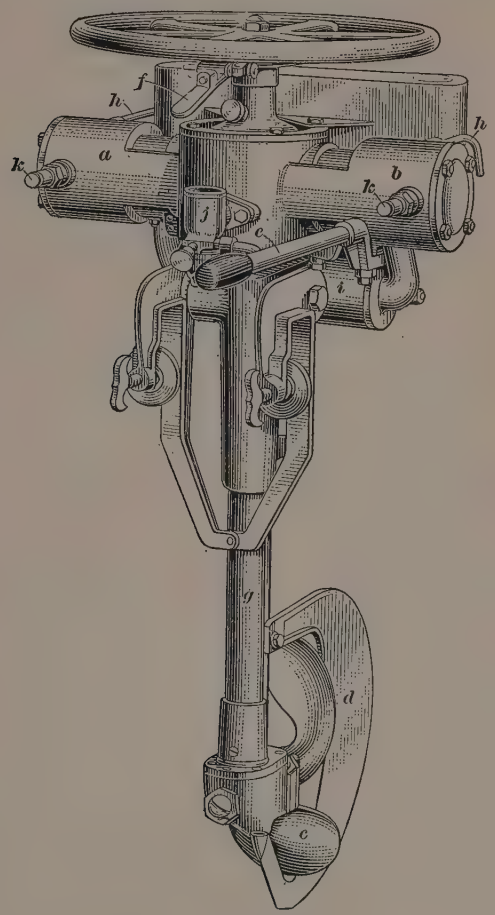


FIG. 11

The engine can be reversed by merely pressing a button on the timer lever *f*. The cylinders are water-jacketed, the water being circulated by a gear-pump that draws water through a metal tube along the main sleeve *g*. The water is discharged

from the water-jackets through the nozzles *h*. The exhaust gases are discharged into a muffler *i*. The carbureter is shown at *j*, and the spark plugs at *k*.

APPLICATION OF FOUR-CYCLE ENGINES

24. Four-cycle marine engines are usually of the vertical type and, in appearance, are very similar to the two-cycle engines. One exception to this, however, is the so-called **V**-type engine, which has one-half of the cylinders located on each side of the crank-shaft and the two rows placed at an angle of 90° or a little less to each other. The **V**-type engine is usually high-powered and built with at least six or eight cylinders. Four-cycle engines of the vertical type are found in practically all of the four- and six-cylinder types where high speed and power are required. Two- and three-cylinder four-cycle engines are used less frequently and single-cylinder engines are very uncommon.

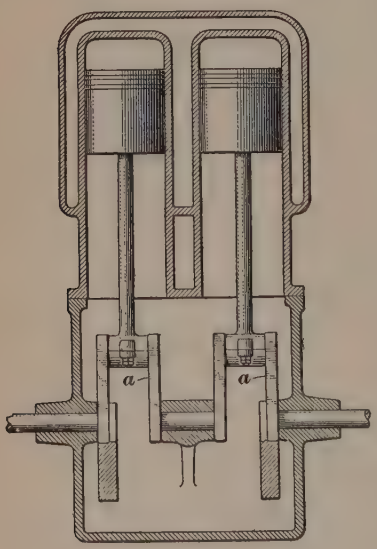


FIG. 12

ARRANGEMENT OF FOUR-CYCLE ENGINE CRANKS

25. Two-cylinder four-cycle marine engines have their cranks arranged side by side, as shown at *a*, Fig. 12, so that the pistons move in unison; that is, they move up or down at the same time. By having the cranks arranged in this manner, an explosion occurs in one of the cylinders for each revolution of the crank-shaft, or each time the pistons move downwards. A uniform application of power to the crank-shaft is thus obtained, although such an engine is hard to balance and will cause vibrations.

26. Three-cylinder four-cycle engines have their cranks arranged at equal intervals around the crank-shaft, or 120° apart, as shown in Fig. 2. On account of the difficulty in balancing the moving parts, this type of engine is not used extensively. The cranks of four-cylinder four-cycle engines are arranged in pairs, the two middle cranks forming one pair, and the two end ones forming the other. The pairs are located on opposite sides of the crank-shaft, as shown in Fig. 13; hence, as the two middle pistons move upwards, the two end ones move downwards, and vice versa. With this arrange-

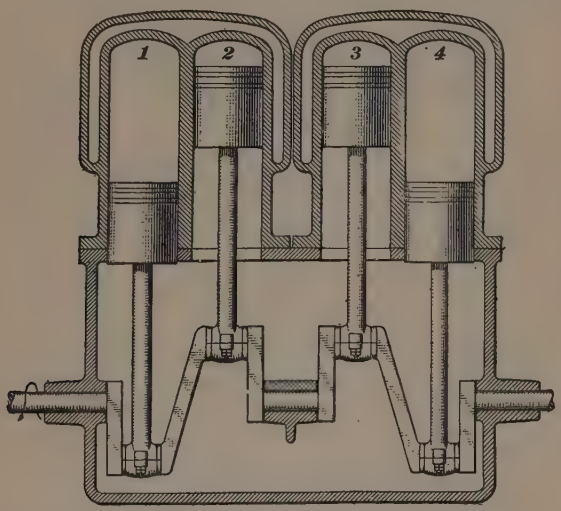


FIG. 13

ment of cranks, there are two different orders in which the explosions can occur in the cylinders. The order of explosions may be either *1–3–4–2* or *1–2–4–3*. In the first case an explosion first takes place in cylinder *1*, then in *3*, then in *4*, and finally in *2*. In the second case an explosion takes place first in cylinder *1*, then in *2*, then in *4*, and finally in *3*. With either of these orders a power impulse occurs in one of the cylinders every half revolution of the crank-shaft. As the two middle pistons move in unison and in a direction opposite from that of the two end pistons, the whole system of moving parts is well-balanced.

27. Six-cylinder four-cycle marine engines have their cranks arranged in pairs, each pair consisting of two cranks located on the same side of the crank-shaft and in the same plane. The usual arrangement is shown in Fig. 14. The

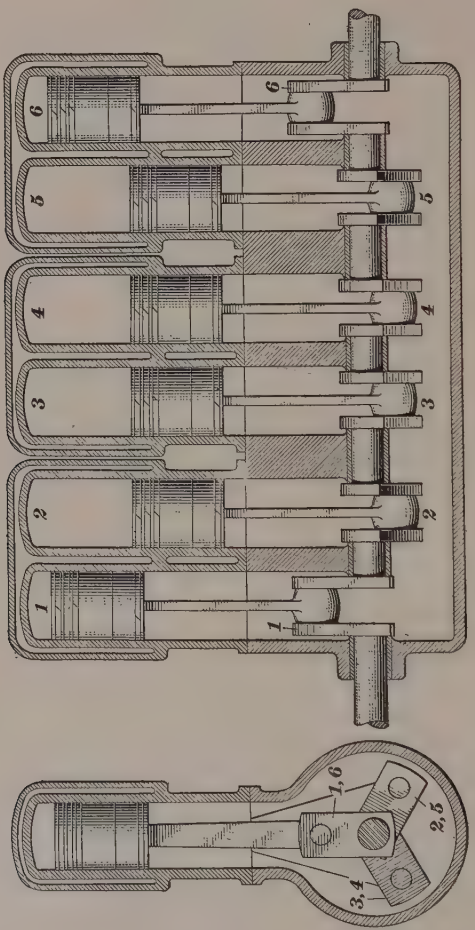


FIG. 14

cranks of cylinders *1* and *6* form a pair, those of cylinders *2* and *5* form a pair, and those of cylinders *3* and *4* form a pair. The pairs are located at equal intervals around the crank-shaft, that is, at an angle of 120° with one another. The two

pistons of each pair move in unison. The impulses in the cylinders of a six-cylinder four-cycle engine occur at intervals of one-third of a revolution; therefore, there are three impulses per revolution. Considering the cylinders as being in pairs corresponding to the three pairs of cranks, the explosions first occur in one cylinder of each pair and then in the remaining cylinders of each pair in the same order. There are four

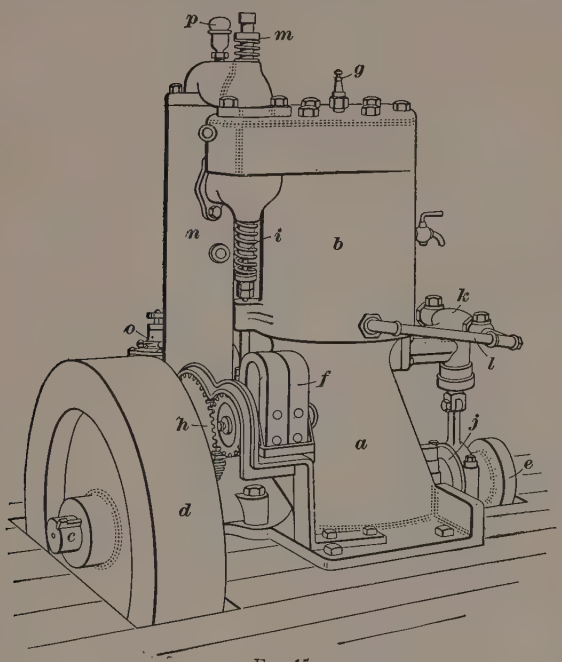


FIG. 15

possible firing orders with the arrangement shown in Fig. 14, as follows: *1–3–2–6–4–5*, *1–3–5–6–4–2*, *1–4–5–6–3–2*, and *1–4–2–6–3–5*.

28. Single-Cylinder Four-Cycle Engines.—It is rather unusual to find the four-cycle type of engine built with a single cylinder for marine service, although it is common in stationary work. One of the few makes of engines of this class, however, is shown in Fig. 15. The frame *a* and the cylinder *b* are cast in one piece and the various attachments

and auxiliaries are bolted to the frame, making a self-contained unit. The crank-shaft *c* carries at one end the flywheel *d* and at the other a coupling *e* by which it is connected to the propeller shaft. The magneto *f* that furnishes the current to the spark plug *g* is driven by the gears *h* from the cam-shaft that operates the exhaust valve *i*. An eccentric *j* drives the plunger of a reciprocating pump *k* by which cooling water is forced through the pipe *l* into the water-jacket of the cylinder.

29. The engine shown in Fig. 15 is of the L-head type, since the exhaust valve *i* and the inlet valve *m* are contained in

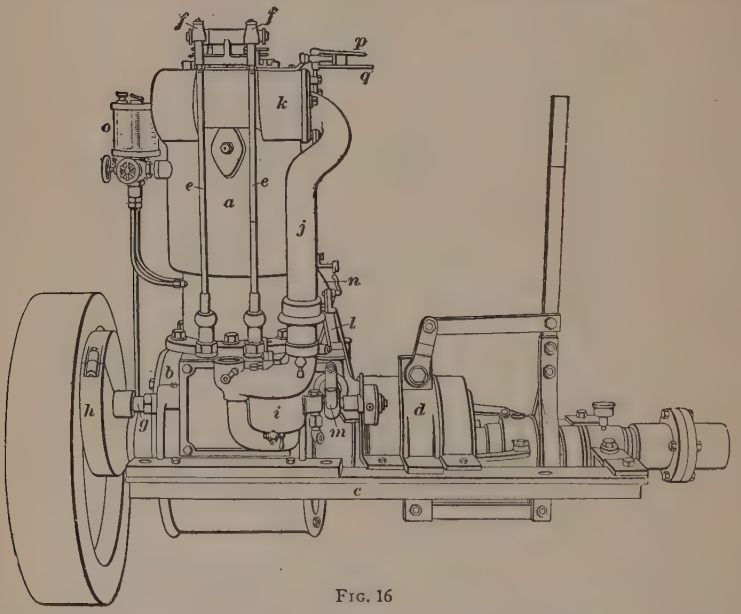


FIG. 16

a chamber at one side of the cylinder. The exhaust gases are discharged into a large pipe *n* that leads to the exhaust pipe. The pipe that leads from the carbureter *o* to the inlet valve is located inside the exhaust pipe *n* and thus the mixture of fuel and air on its way to the cylinder is subjected to the heat of the exhaust gases, which aids in the vaporization of the fuel. The priming cup *p* is used when the engine is to be started in cold weather. No reversing mechanism is supplied with this

engine, but a reversing propeller is used, thus enabling the direction of motion of the boat to be reversed without reversing the engine.

30. Another single-cylinder four-cycle engine is shown in Fig. 16. The cylinder *a* is bolted to the frame *b*, which is carried by the supports *c* that carry the engine and a reversing gear *d* and join them into one unit. The distinctive feature of this engine is the location of the valves in the head of the cylinder. The sectional view, Fig. 17, indicates the relative location of the valves. The exhaust valve, shown at *a*, is closed by the spring *b*, and the exhaust gases pass out through the opening *c* which is surrounded by a water-jacket *d* connected with the water-jacket of the cylinder *e* as shown. The inlet valve, which is similar in construction to that of the exhaust valve, is located in the opening *f*, and the fuel mixture passes to the inlet valve through the intake passage *g*. The movement of the valves is obtained by cams that act on the push rods *e*, Fig. 16, the rods acting on horizontal rocker-arms *f* pivoted on a bracket bolted to the cylinder head. The opposite ends of the rocker-arms engage with the valve stems. The valves are closed by the action of coiled springs. The cam-shaft *g* is driven from the crank-shaft by two-to-one gearing inside the case *h*.

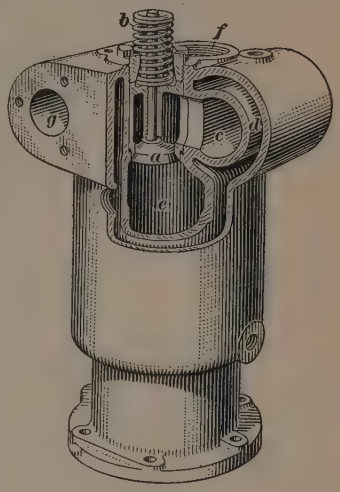


FIG. 17

31. The carbureter *i*, Fig. 16, is located close to the crank-case and from it a pipe *j* leads to the intake passage *k*. The exhaust passage is on the opposite side of the cylinder. The cooling water for the cylinder is circulated by a pump *l* that is driven from an eccentric *m* on an extension of the cam-shaft. The water is drawn in by the pump and forced to the cylinder

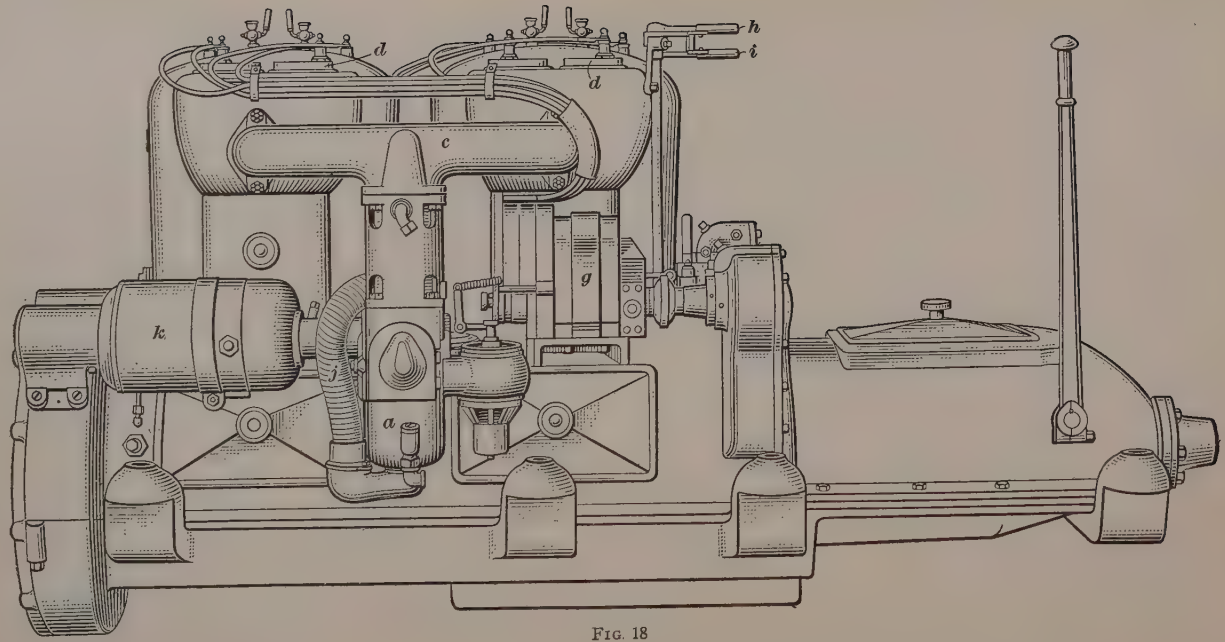


FIG. 18

jacket through the pipe *n*. Lubrication of the main bearings and piston is effected by distributing pipes from the sight-feed oil cup *o*. Splash lubrication serves for the piston pin and the crankpin. Spark and control levers *p* and *q* enable the speed of the engine to be adjusted to the load.

32. Four-Cylinder Four-Cycle Engine.—A self-contained engine of the four-cycle type is shown in Fig. 18, and a part cross-sectional view of the cylinder is given in Fig. 19. The cylinders, of which there are four, are cast in pairs and are of the T-head type. The base of the engine, to which they are bolted, is a continuous rigid casting, strongly ribbed, carrying the crank-shaft bearings and the clutch and reversing gear. All the moving parts of the engine are completely enclosed, but access to the crank-case is easily obtained by removing light hand-hole covers that are held in place by knurled nuts and studs. These covers are placed on both sides of the engine. The base is provided with four lugs on each side, through which pass the bolts by which the engine is secured to the foundation timbers.

33. In the engine shown in Figs. 18 and 19, one carbureter *a* serves all four cylinders. Hot water from the jacket *b* of the exhaust pipe is led through a suitable pipe to the carbureter, where its heat assists in vaporizing the fuel. The gaseous mixture is then conveyed through the intake pipe *c* to the inlet valves, all four of which are on one side of the cylinder and are operated from a cam-shaft on that side. The valve tappets and push rods are entirely enclosed, but the inlet valves may be inspected after removing the plugs *d*. The exhaust valves *e* are located on the exhaust side of the engine and are opened by the action of the cams on the cam-shaft *f*. Current for ignition is furnished by a high-tension magneto *g*. The levers *h* and *i* provide for hand control of both the spark and the throttle.

34. Lubrication of the engine shown in Figs. 18 and 19 is effected by a force-feed system. The oil is drawn from a sump or pit by a positive-pressure pump of the gear type and is forced through a filter to the various bearings. The crank-

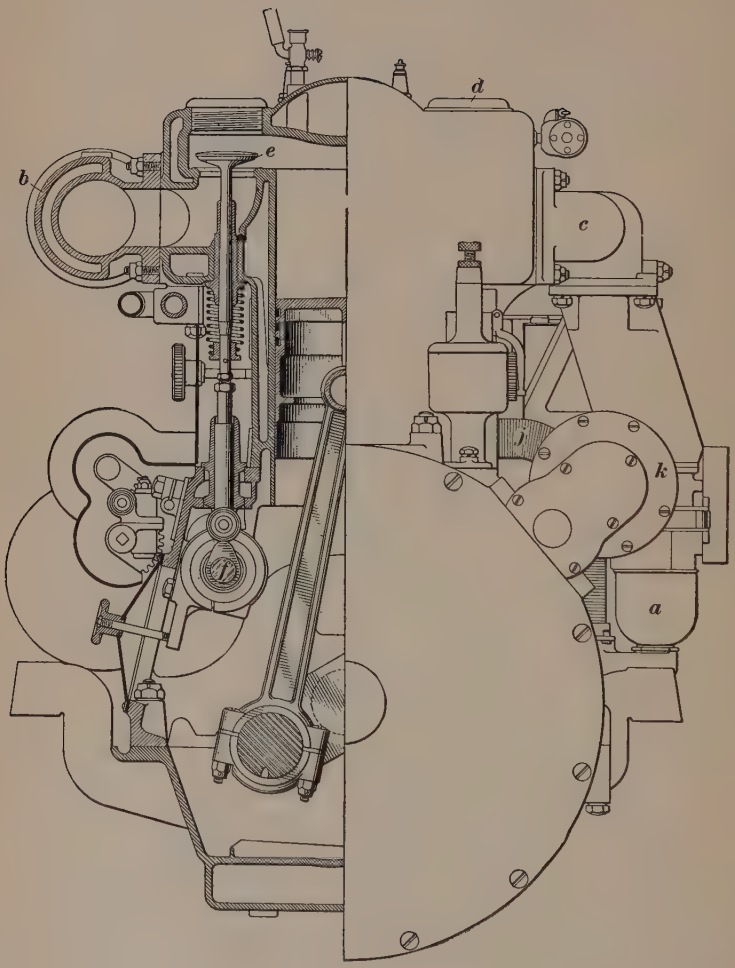


FIG. 19

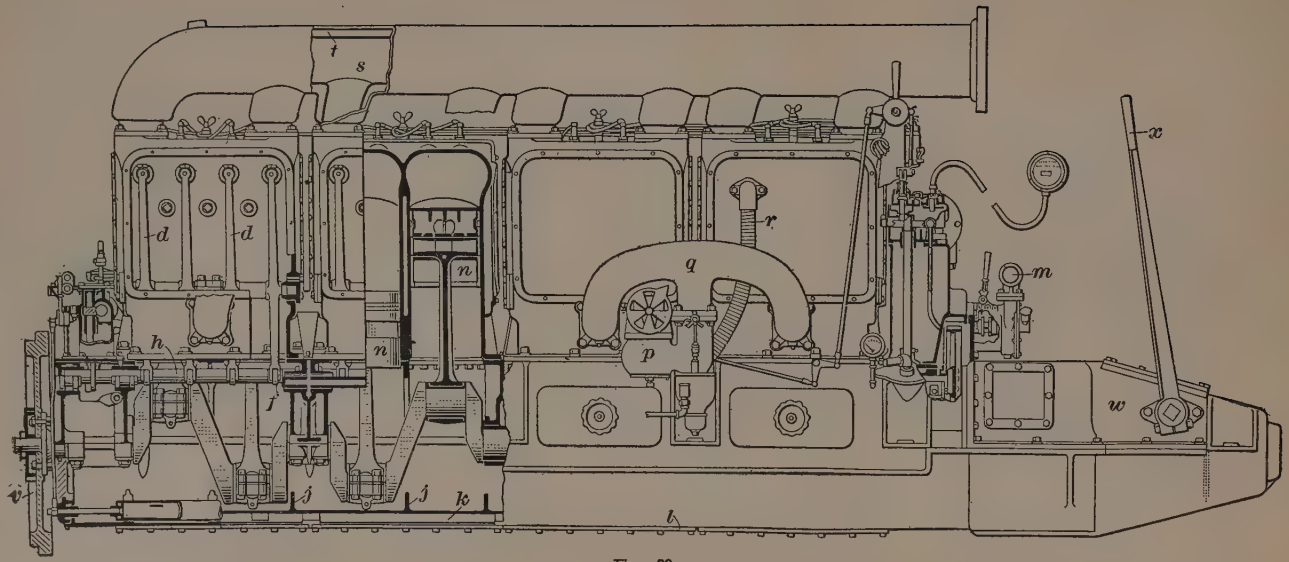


FIG. 20

shaft is drilled for carrying the oil to the connecting-rods. The oil in its circulation is passed through a cooling system so that a low, even temperature is maintained. The cooling is effected by the water that is taken in by a gear-pump and afterward used to cool the cylinders and exhaust manifold. The flexible tube *j* connected to the bottom of the carbureter communicates with the interior of the engine base and all oily or smoky vapors are thus drawn away. The engine is fitted with an electric starter *k* that carries a pinion which meshes with a steel ring on the flywheel.

35. Eight-Cylinder Four-Cycle Engine.—The side view, Fig. 20, shows an eight-cylinder engine of the four-cycle type, partly in section, and Fig. 21 shows a cross-section of the cylinder of the same engine. The distinctive feature of this engine is the location of the valves. They are placed horizontally, as indicated by the exhaust valve at *a*, and open directly into the combustion chamber *b* at the top of the cylinder. The engine thus belongs to the valve-in-head class, but the valve stems are horizontal instead of vertical. The valves are opened against the pressure of the double-coil springs *c* by the action of the rocker-arms *d*. These are placed vertically and are pivoted below their middle points, as at *e*. At their lower ends they carry rollers *f* that bear against cams *g* on the cam-shaft *h*, which runs lengthwise of the engine and is driven by two-to-one gearing from the crank-shaft *i*.

36. The cylinders of the engine shown in Fig. 20 are cast in pairs and are bolted to the frame that carries the main bearings and forms the crank-case. The cranks of each pair of cylinders are 180 degrees apart and have no bearing between them. The crank-shaft has a bearing at each end of the crank-case and three intermediate bearings, all of which are supplied with oil under pressure through passages cored in the crank-case. The crank-arms of the crank-shaft are drilled diagonally and oil is forced through these passages to lubricate the large ends of the connecting-rods. The oil pan at the bottom of the crank-case is provided with transverse webs *j*, dividing it into as many troughs as there are connecting-

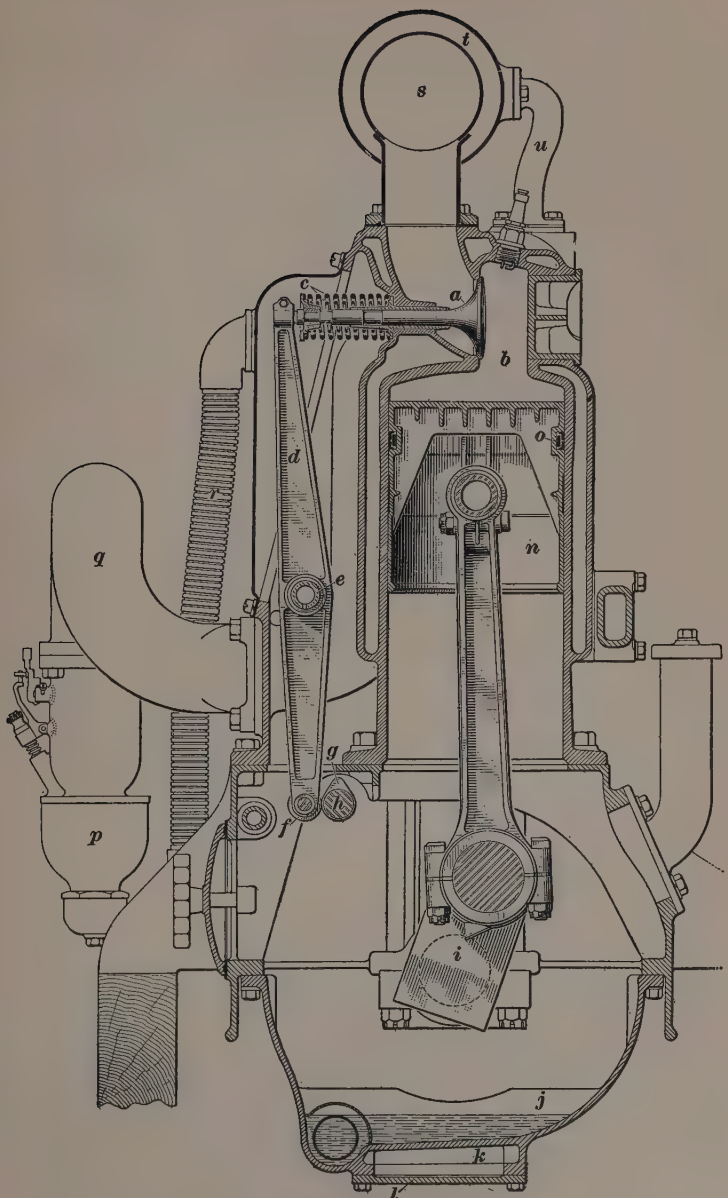


FIG. 21

rods, and each rod is thus supplied with oil of the same depth. At the side of each trough is a tube with a slot, allowing the oil to overflow from the pit to a sump. This tube can be rotated from the outside, and so any desired level may be maintained in the oil pits.

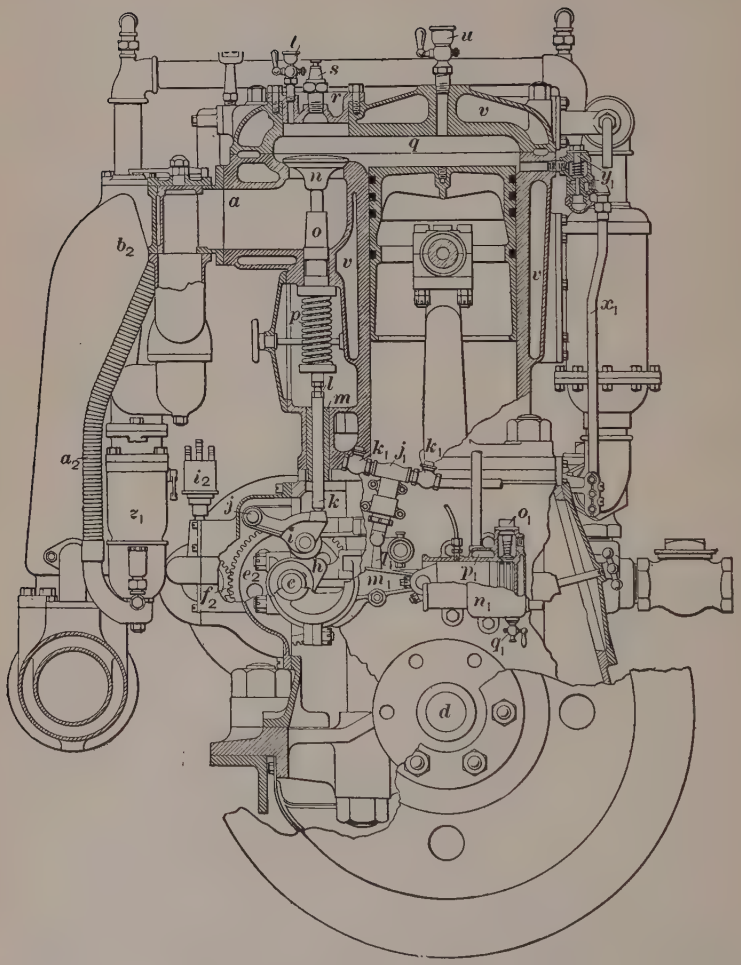
37. Beneath the bottom of the oil pan, Figs. 20 and 21, is a cored space *k* closed by cast-iron covers *l*, through which the water discharged from the circulating pump *m* flows. The purpose of circulating water beneath the oil pan is to keep down the temperature of the oil and increase the efficiency of lubrication. The oil is drawn from the oil sump by a pump driven from the cam-shaft at the after end and is discharged through a strainer into a tank. At the forward end of the cam-shaft is a worm-driven pressure pump that takes oil from the tank and discharges it under pressure through oil pipes and cored passages to the main bearings, cam-shaft bearings, and auxiliaries. A pressure gauge mounted on the discharge line shows the oil pressure that is maintained in the system. The piston *n* is lubricated by the splash system. It is stiffened with ribs and is fitted with a single three-piece ring *o*.

38. The mixture of fuel and air is supplied by two carbureters, as shown at *p*, Figs. 20 and 21, each carbureter serving two pairs of cylinders. From the carbureter the explosive mixture flows to the manifold *q*, from which it passes to the intake passages of the cylinders. The flexible pipe *r* connects the air passage of the carbureter with the interior of the engine through the covers that protect the valve action, and thus all gases and vapors are removed from the interior. The exhaust gases are discharged into the exhaust pipe *s*, which extends aft, that is, to the rear, along the tops of the cylinders. This pipe is provided with a water-jacket *t* that receives water from the cylinder jackets through the pipe *u*. The dual system of ignition is used, the current being supplied by two high-tension magnetos. Starting is accomplished by a motor geared to the flywheel *v*, the current being obtained from a storage battery. The reverse gearing and clutch are contained inside the casing *w* and are operated by the lever *x*.

HEAVY-DUTY ENGINE

39. General Features.—The more generally known class of marine gas engines has a medium bore and stroke and operates on gasoline at a high rotative speed. These conditions allow for a fairly light construction, but an engine of this type cannot perform properly in the service that must be met by a boat that must operate under different loads; for the engine of such a boat must be able to deliver a maximum of power at all times. To meet these conditions, the heavy-duty engine operating on either gasoline or kerosene has been developed. Such an engine must have a relatively large bore and long stroke to develop a maximum of power per stroke, and is generally designed to turn a propeller that is much larger than is used on boats intended for lighter work, such as small pleasure boats and yachts. The combination of low rotative speed and large propeller develops a powerful drive at a low boat speed.

40. The heavy-duty engine shown in side elevation in Fig. 22 and in section and end elevation in Figs. 23 and 24 is of the four-cylinder four-cycle type, operating on either gasoline or kerosene. If gasoline alone is used, the fuel equipment of the engine is that of the ordinary gasoline engine; but if kerosene is used, special equipment must be provided. The temperature at which kerosene vaporizes is much higher than that for gasoline, so that it is necessary to use a special manifold cover, which, heated by contact with the exhaust gases, raises the temperature of the mixture of air and kerosene to a point at which the kerosene will vaporize readily. Because of this high initial temperature, the heat of compression, if not controlled, would be likely to cause preignition; therefore, a small quantity of fresh water is carried from a separate tank into the cylinder, on each suction stroke. This water is immediately changed into vapor, which, in addition to reducing the heat of compression, retards combustion during the expansion stroke, so that full advantage is taken of a long power stroke. Four-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m_1
e_2
f_2
h
c
d
y_1
x_1

Fig 23

cylinder engines of this type are rated at as high as 100 horsepower, while six-cylinder engines of the same design will deliver as much as 150 horsepower.

41. Valve Operation.—The cylinders of the engine shown in Figs. 22, 23, and 24 are cast in pairs, so that each pair may be removed from the engine base without disturbing the others. The inlet port *a* and the exhaust port *b*, Fig 22, are cast in the engine block, the inlet port being shown at *a*, Fig. 23, which is a section taken at right angles to the center line of the engine, through the cylinder nearest the flywheel. All ports are on the same side of the cylinder, which makes it possible to operate both sets of valves from a single cam-shaft *c*. The cam-shaft is driven at half the crank-shaft speed from the crank-shaft *d* through a train of reducing gears *e*, *f*, and *g*, Fig. 24. Each cam *h*, Fig. 23, operates a valve lifter *i* that swings on a pin *j*. The lever gives a vertical motion to a push rod *k* that forms contact with the valve stem by an adjusting screw and locknut *l*. The push rod slides in a bushing *m* that may be replaced when worn.

42. Cylinder and Valves.—The valve *n*, Fig. 23, is of the usual mushroom or poppet type and is kept in position by a guide *o* that is fitted into the engine block and may be removed after the valve has been withdrawn. The lower end of the guide forms a collar that bears against the engine casting and serves as a seat for one end of the valve spring *p*, the other end of which rests in a collar fastened to the lower end of the valve stem. The piston, which is of the trunk type, has a flat head that is nearly level with the valve seat when the piston is on the upper dead center. The compression space is formed beneath the cylinder head *q*. The valve may be removed through an opening cast in the cylinder head directly over the valve seat. The opening is closed by a plug or a cover-plate *r* that is bolted to the cylinder head. The plug over the intake valve contains the spark plug *s*, and a priming cup *t* is provided, which may be used also to relieve the compression when the engine is being started. A second cup *u* is sometimes located over the center of the piston to

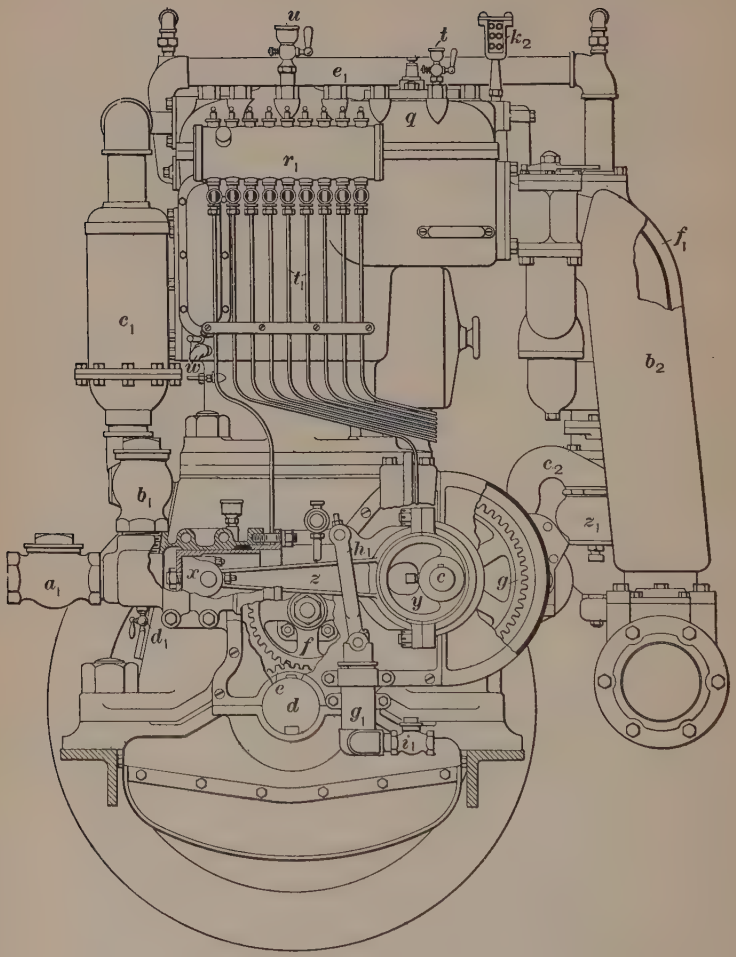

FIG. 24

test the ignition when the engine is in operation, or for the injection of lubricating oil. In cold weather after the engine has stood for some hours, a small quantity of lubricating oil may be poured onto the piston through this cup, thereby assuring good compression and ample lubrication from the start. The water-jackets v are formed in the cylinder and cylinder-head castings, and a drain cock w, Fig. 24, is used for drawing off the water from the water-jackets.

43. Pumps.—In engines of the heavy-duty type it is necessary to use pumps for the circulation of cooling water and lubricating oil. A cooling-water pump x, Fig. 24, is located at the rear of the engine and is driven from the cam-shaft c by an eccentric y through an eccentric strap and eccentric rod z. The water enters the pump through a check-valve a_1 and is forced through a discharge valve b_1 into an air dome c_1 from which the water is delivered through a manifold to each cylinder block. A drain cock d_1 is used for draining the pump when it is not in use. The overflow from the water-jacket is delivered through a pipe e_1 to a water-jacket f_1 surrounding the exhaust manifold. A bilge pump g_1 for removing water from the boat is driven by the eccentric y through a link h_1 that is fastened to a lug on the eccentric rod z. The pump draws water through a check-valve i_1 from the space between the floor and the bottom of the boat and discharges it directly through the hull past a check-valve, not shown. An oil pump j, Fig. 23, is used for returning the oil from the oil well, located in the crank-case, to the oilers. Check-valves k_1 control the direction of flow of the oil. A link l_1 connects the oil-pump plunger to an eccentric strap and arm m_1 driven by an eccentric on the cam-shaft c.

44. Air Compressor.—Compressed air for starting the engine, for sounding the whistle, and for the other uses to which it may be applied on a boat, is furnished by an air compressor n_1, Fig. 23. The compressor is driven from the cam-shaft through an eccentric strap and rod m_1, and operates whenever the engine is running. Air is drawn into

the compressor past a check-valve that is not shown and is discharged past the check-valve o_1 into a tank or receiver in which a pressure of from 75 to 125 pounds is maintained. The size and location of the receiver will depend on circumstances; but it should be sufficiently large to insure a supply of starting air under all conditions, and should be located as close as possible to the engine. When air is compressed a certain amount of heat is generated; therefore, the air compressor is surrounded by a water-jacket p_1 supplied with water from the main cooling system and drained by a drain cock q_1 located at the lowest point of the jacket.

45. Lubrication.—Lubrication of the engine shown in Figs. 22, 23, and 24, is accomplished partly by gravity feed and partly by forced feed. The oil circulating pump j_1, Fig, 23, delivers the oil to both a gravity feed tank r_1, Fig 24, and a force-feed tank, or oiler, s_1, Fig. 22, each tank having separate delivery pipes t_1 leading to the parts to be oiled. The gravity-feed system supplies oil to those parts that are not under very great pressure, such as the cam-shaft, while the force-feed lubricator supplies oil to those parts under greater pressure, such as the crank-shaft. The lubricating pump located in the oiler s_1 is operated by a vertical shaft u_1 that is driven by a bevel gear v_1 on the end of the cam-shaft. Adjusting nuts on the vertical shaft make it possible to make any changes that may become necessary through wear.

46. Air Distribution.—The compressed air used for starting purposes is controlled by a valve w_1, Fig. 22, located on the lower end of the vertical shaft u_1, which distributes the starting air to the proper cylinders. Air from the compressed-air receiver is admitted to the air valve, which controls the flow of air to a set of pipes, not shown, leading to the several cylinders. The vertical section x_1, Fig. 23, of each of these pipes is attached to a check-valve y_1 that admits air to the cylinder but prevents the return of the air from the cylinder to the pipe line. The purpose of the valve w_1 is to arrange the distribution of air so that the compressed air will be

delivered to each cylinder at the beginning of what would be the power stroke, when both the intake and exhaust valves are closed, and to cut off the compressed air at the proper time. The operation of this valve must be very accurately timed, as the flow of starting air must correspond exactly with the operation of the valves of each cylinder.

47. Carbureter.—The type of carbureter used in the heavy-duty engine will depend on the fuel used. If gasoline alone is used, the engine is equipped with a standard type of gasoline carbureter; but if kerosene is used as fuel, a special carbureter must be furnished. Kerosene does not vaporize freely and therefore it must be heated sufficiently to cause it to vaporize and mix readily with the air, when it forms an excellent fuel for internal-combustion engines. It is customary to equip the kerosene engines either with two carbureters—one for gasoline and one for kerosene—or with a carbureter that is divided in such a way as to serve for both gasoline and kerosene. The engine is started on gasoline and is operated on this fuel until thoroughly warmed up, when the fuel connection is changed so that kerosene will be supplied to the carbureter. When separate carbureters are used, this is accomplished by adjusting valves; but the engine shown in Fig. 22 is equipped with a carbureter of the divided type so that the change is made by moving a lever that alters the conditions within the carbureter.

48. To assist in the vaporizing of either fuel, it is customary to pass the incoming air over or through some part of the engine. The main air intake of the carbureter z_1, Figs. 23 and 24, is connected by a flexible tube a_2 to a space that surrounds the exhaust manifold b_2, and the air is heated as it passes through this space by coming in contact with the hot walls of the manifold. The auxiliary air supply is drawn from the crank-case through a rigid connection c_2. This air enters the crank-case through the breather pipe and is heated by contact with the walls of the crank-case, cylinders, and pistons. When kerosene is used, the vapor is drawn from the carbureter into a chamber, not shown, that is heated by

the exhaust manifold, and in which the gas mixes with a very small quantity of fresh water that is allowed to drip into the space. The water is immediately converted into steam by the heat of the surrounding metal and serves to retard the formation of carbon and to extend the period of combustion over a portion of the power stroke.

49. Ignition.—The engine is equipped with a dual-ignition system consisting of a battery circuit and a magneto circuit, each of which is complete in itself. A magneto d_2, Fig. 22, is driven from the cam-shaft through gears e_2 and f_2, Fig. 23, and a shaft g_2, Fig. 22, that is connected to the magneto by the flexible joint h_2. It is necessary for the magneto to make three revolutions for every two revolutions of the crank-shaft, and therefore the diameter of the pinion f_2 is made one-third that of the gear e_2. The gear e_2 then acts as an idler between the pinion and the crank-shaft and a ratio of three to two is obtained between the crank-shaft and the magneto. The distributor i_2 used in connection with the battery circuit is driven through the bevel gears j_2, and wires from both the magneto and the distributor are carried across the top of the engine in the tube k_2, which serves as a protection to the wires. Outlets in the tube are provided opposite the several spark plugs, so that the proper connections may be made through the tube walls. The engine is started on the battery circuit, but is switched to the magneto circuit when running.

50. Governor Control.—The governor of the heavy-duty engine shown in Fig. 22 is horizontal and is located at l_2. It is shown in longitudinal section in Fig. 25 (a). The governor weights a are fulcrumed at b and revolve with a spindle c that is driven by a gear d from the cam-shaft. The spindle is supported by a sleeve bearing e that has sufficient length to overcome the side thrust of the driving gears. As the speed of the engine increases, the weights swing outwards around their fulcrums, and the rollers f located at the inner ends of the weight arms press against the cap g on the end of the push rod h. The movement of the weights is transmitted by

the push rod to a rocker-arm i, the shaft of which passes through the governor housing. Pressure due to the action of the weights is carried by a thrust bearing j that prevents endwise motion of the spindle, and a roller bearing k between the spindle and the cap reduces friction at that point.

51. An outward movement of the governor weights forces the push rod to the right against the resistance of a coil spring l, Fig. 25 (a), which is compressed between an adjusting nut m and a rack n. When the speed of the engine decreases, this spring forces the push rod to the left and

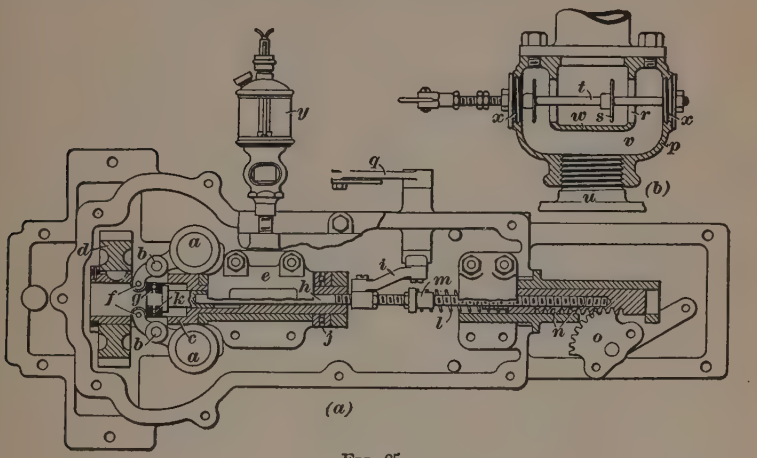

FIG. 25

returns the weights to their normal position. The initial compression of the spring may be adjusted while the engine is in operation by means of a toothed segment o, shown at m_2, Fig. 22. A clockwise movement of the segment moves the rack to the right and relieves the compression in the spring. The movement of the push rod is transmitted to a throttle valve p, view (b), Fig. 25, through a rocker-arm q, shown at n_2, Fig. 22, and a reach rod o_2 that is connected to the valve.

52. The throttle valve, shown in Fig. 25 (b), is composed of the valve body p containing the ports r, the valves s, and a valve stem that passes entirely through the valve body

from end to end. The mixture of fuel and air enters the valve body from the carbureter through a connection u and passes into a chamber v from which the flow is controlled by the valves s operated by the governor. The valve body is divided into two separate chambers or compartments by an inner shell w cast integral with the outer shell. The ports r are located in opposite sides of the inner shell and the gases must pass from the carbureter to the center of the valve body through these ports. The position of the valves s is such that the gases in passing through the ports tend to hold one valve open and close the other, so that the pressure on the valves is equalized.

53. The amount of gas that passes through the ports r, view (b), Fig. 25, is controlled by the openings between the valves s and their seats. An outward movement of the governor weights, due to increased engine speed, moves the valves closer to their seats, and the flow of gas is lessened, thus reducing the power of the engine and causing a decrease of speed. The valve stem t slides in two plugs or bearings x screwed into the valve body. The holes for the plugs are made large enough to permit the removal of the valves when the plugs have been taken out. The only part of the governor that needs direct lubrication is the spindle bearing, which is supplied with oil from the sight-feed lubricator y, view (a), as sufficient oil will escape from this bearing to lubricate the other moving parts inside the governor housing.

54. Speed Control.—The speed of the engine shown in Fig. 22 is controlled by adjustments of the spark and throttle, which may be arranged to suit the construction of the boat in which the engine is installed. In any case, the air-starting, carbureter, and spark controls should be centralized. The direction of rotation of the propeller shaft p_2 is controlled by a reversing gear q_2 through a handle r_2. For go-ahead rotation the handle is moved toward the engine, thus causing an expanding clutch s_2 to engage, with the result that the engine and the propeller shaft turn as a unit, both rotating in the same direction. A movement of the handle away from the

engine disengages the clutch and tightens a brake band t_2, through the level u_2, holds the gear drum stationary, and causes a set of planetary gears inside the drum to give the propeller shaft a direction of rotation opposite to that of the engine shaft. When the handle r_2 is in a vertical position, both the clutch and the brake band are released and the engine is free to turn without rotating the propeller shaft.

HIGH-SPEED CRUISER ENGINE

55. Purpose.—Light cruisers and smaller boats intended for comparatively high speeds require engines of relatively small bore and short stroke, having both high power and high speed. An engine of this kind is shown in Fig. 26. It is of the six-cylinder four-cycle type and is capable of developing about 220 horsepower when running at 1,500 revolutions per minute. It is made either right-hand or left-hand, so that, in cases where a boat is to be equipped with two propellers, both a right-hand and a left-hand engine can be installed, which is a convenience where space is limited. This class of engine can also be used in boats built for fairly high speeds and all-around service.

56. Design.—In design the engine shown in Fig. 26 has the usual characteristics of the marine gasoline engine. The cylinders are cast in pairs, which are bolted to a single base extending the full length of the engine. Each pair of cylinders is covered by a casting that forms the cylinder heads for that pair and both cylinders and cylinder heads are surrounded by water-jackets formed in the casting. The valves, which are of the poppet type, are located in the cylinder heads and are all driven from a single cam-shaft through the push rods *a* and rocker-arms located under the covers *b*. The crank-shaft is supported by seven bearings, which gives a bearing between each pair of cranks, as well as at each end, and prevents the possibility of springing the shaft out of line. A housing *c* cast with the base surrounds the flywheel and a plate *d* bolted to the housing closes the open end, so that the

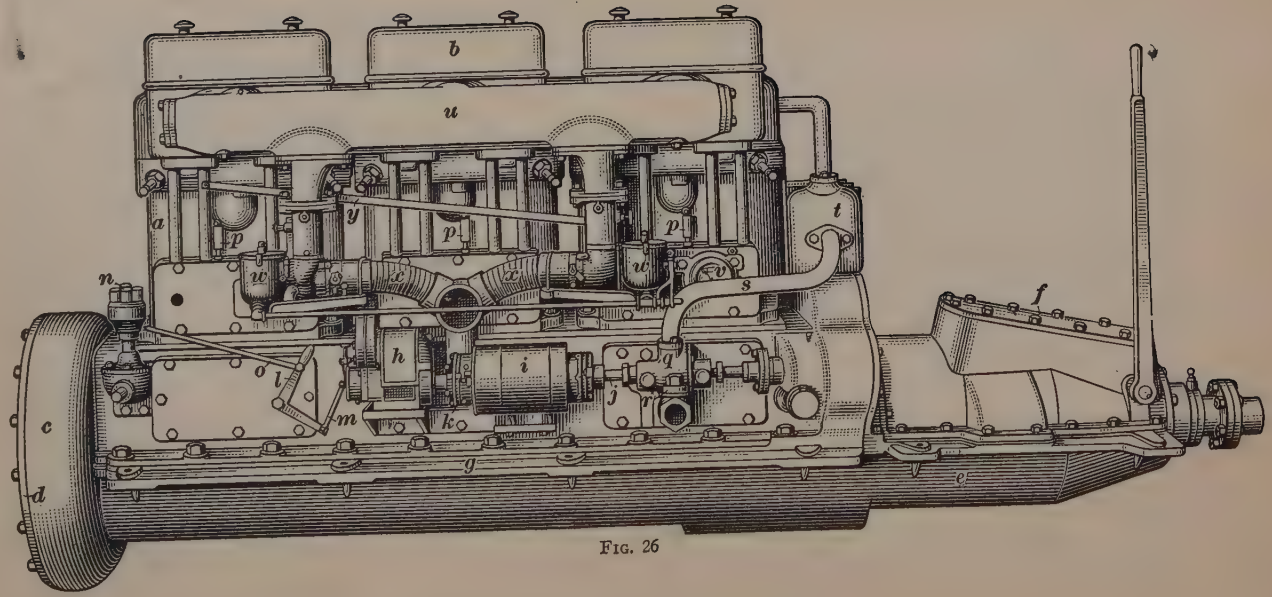

FIG. 26

flywheel is completely enclosed. The reversing gear is located in a housing *e*, the lower part of which is an extension of the engine base, and the upper section is bolted to it. A cover-plate *f* may be removed for the inspection of the mechanism. The engine is supported on its bed by two plates *g*, one of which is bolted securely to each side of the engine base.

57. Electrical Equipment.—The engine shown in Fig. 26 is equipped with a high-tension magneto *h*, and a generator *i*. The magneto is used for the ignition current and the generator supplies current for charging a storage battery and for lighting purposes when the engine is running. Starting the engine is accomplished by an electric starter located on the farther side of the engine and geared to the flywheel. Both the magneto and the generator are driven by a shaft *j* through flexible connections *k*, one of which is located on each side of the generator. These permit a freedom of alinement that would not be possible if the shaft were continuous from end to end. With this arrangement only one spark plug for each cylinder is used, but it is possible to equip the engine with two spark plugs for each cylinder, so that the battery circuit and the magneto circuit can be used independently of each other or both together. The advantage of the latter system lies in the fact that one system can always be held in reserve for use in case the other system should fail to operate. The time of ignition is controlled by the bell-crank lever *l*, which is connected to the magneto by the link *m* and to a distributor *n* by the link *o*. The wiring is contained in a sheet aluminum housing supported on brackets *p* attached to the engine.

58. Cooling Water.—Cooling water is forced through the various water-jackets by a gear-type water-circulating pump *q*, Fig. 26, which also is driven by the shaft *j*. Water is drawn in through the check-valve *r* and discharged through the pipe *s*, which is enlarged to form a cooling jacket *t* for the lubricating oil. The water then passes through a continuation of the pipe to a manifold that surrounds the exhaust manifold on the other side of the engine and therefore cannot

be seen. Separate pipes lead from the water manifold to the lower end of the water-jacket of each block and thus deliver the cooling water to the coldest portion of the cylinder. In this way the cooling water is warmed, first by absorbing heat from the lubricating oil and then by the heat of the exhaust gases. Passing the comparatively cold water around the exhaust manifold serves to lower the temperature of the gases and decrease their volume, thus reducing the noise of the exhaust. After circulating through the water-jackets of the cylinders and cylinder heads, the cooling water is discharged through a manifold *u* that surrounds the intake manifold. This serves to heat the incoming gases before they enter the cylinders.

59. Lubrication.—The lubricating system of the engine in Fig. 26 is of the dry-sump type; that is, the lubricating oil is retained in a separate tank instead of in the crank-case. The required amount of oil is drawn from this tank and fed under pressure to the engine by a pump, located on the farther side of the engine, that is capable of delivering more oil than can possibly be required. A by-pass is provided, which is regulated to allow the proper amount of oil to be delivered. Oil is forced into the crank-shaft, which is drilled for the purpose, and delivered to the main bearings and crankpin bearings. More oil is delivered than is required and the excess moves upwards under pressure through tubes on the connecting-rods to the wrist pins. Excess oil is sprayed onto the cylinder walls from this point. Separate pipes deliver the oil to the rocker-arms. The oil that is not used drips back into the crank-case and collects in the oil sump, from which it is drawn by a second pump that is larger than the delivery pump. The extra size of the sump pump prevents any oil from collecting at this point and therefore insures a dry crank-case. The oil that has been used is forced through a copper coil approximately 8 feet long, located in the water-jacket *t*, where it is cooled before returning to the supply tank. This method insures an even distribution of oil to all parts of the engine and avoids

the troubles met by the splash system in rough weather. A gauge *v*, which may be located on the engine or at some remote point, such as the bridge, indicates the pressure under which the oil is being supplied to the engine and gives warning of any irregularity in the feed.

60. Fuel.—The engine shown in Fig. 26 is operated on gasoline fed to the cylinders through two carbureters *w*, each of which supplies three cylinders. An even distribution of fuel throughout the length of the manifold is obtained in this way, and there is no danger that one cylinder will rob the next of its charge. Air is taken in through the crankcase, where it is warmed, and is delivered to the carbureters through the flexible tubes *x* and a Y connection bolted to the engine bed. After it enters the intake manifold, the mixture of gasoline and air is heated by the discharge from the water-jackets, which surrounds this manifold, and sufficient heat is absorbed by the gases to insure perfect vaporization. The gases, after burning and expanding in the cylinders, are discharged into a manifold, where they are cooled by the incoming cooling water and are then passed through the muffler to the atmosphere. The rod *y* connects the throttle control of the two carbureters so that they operate together.

MARINE DIESEL ENGINES

Serial 2046 Edition 1

TYPICAL MARINE DIESEL ENGINES

CLASSES OF DIESEL ENGINES

1. Heavy-duty marine engines, such as those used for driving fishing boats, freighters, tank ships, merchant vessels, naval craft and submarines, are invariably built to use fuel oils of the heavier grades, because these are cheaper and more plentiful than gasoline and kerosene. The oils commercially known as solar oil, tar oil, distillate, fuel oil, and even crude petroleum may be used in the heavy-oil types of engines. Such oils have specific gravities that correspond to from 14 to 40 degrees Baumé; but it is probable that the greater number of marine oil engines use fuels having a range of from 20 to 34 degrees Baumé. The heating value of such oils is in the neighborhood of 18,000 to 18,500 B. t. u. per pound.

2. Heavy-duty marine engines are of both the two-cycle and the four-cycle type, and are known as Diesel, semi-Diesel, low-compression, Hvid or Brons engines, and solid-injection engines, according to their methods of operation. The true Diesel engine is one that takes into the cylinder a charge of pure air, compresses it to a high pressure and corresponding temperature, and then injects a spray of fuel into this heated air, the temperature of compression being sufficient to ignite the explosive mixture formed by the mingling of the oil spray and the air. The semi-Diesel or low-compression engine also compresses a cylinderful of air and injects a spray of fuel oil

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into the compressed air; but the compression is not so high as in the Diesel and ignition is not entirely due to the temperature of the compressed air. Instead it is brought about by a heated lip, bulb, or plate against which the oil is sprayed and which is kept hot by the successive explosions of the charges.

3. The Hvid, or Brons, type is a high-compression engine, like the Diesel, and ignition is caused by the compression temperature; but the injection of the fuel is distinctive, the fuel being first admitted into a primary combustion chamber in which the lighter and more volatile part is gasified and then ignited by the high temperature of compression in the cylinder. The resulting explosion raises the pressure in the primary chamber sufficiently to force the remainder of the fuel charge in a finely atomized condition into the cylinder where complete combustion takes place. This method of injecting the fuel without the use of an air compressor is often called airless fuel injection. In the solid-injection class are included those engines in which the fuel is injected directly into the cylinder by a fuel pump without the aid of injection air.

4. Following the introduction of the Diesel oil engine and its constantly increasing use, especially for ship propulsion, the tendency in modern design in the United States has been to preserve the essential features of European types, profit by the experience gained in their operation, and adapt them to American shop practice and operating conditions. Most of the marine Diesel engines made in this country are built under patents held by foreign manufacturers. There has been a strong tendency toward standardization of the main parts of both the four-cycle and the two-cycle engines and this tendency becomes more pronounced as the industry develops. Both four-cycle and two-cycle engines are built for marine use, the latter being preferred for very large ship installations, because of the saving in floor space and in weight per horsepower, with a correspondingly low cost of manufacture. On the other hand, the four-cycle engine is slightly more efficient in operation, as the two-cycle engine requires an auxiliary air pump for scavenging and refilling the cylinder.

For large engines, such a pump requires considerable power for its operation, as it must supply a volume of air greater than the volume of the cylinder for thorough scavenging, thereby reducing the mechanical efficiency of the engine. The largest oil-engine unit for marine service built in this country has a capacity of 4,000 horsepower, whereas, in Europe, marine Diesel engines of 10,000 horsepower capacity are successfully built.

FOUR-CYCLE MARINE DIESEL ENGINES

ENGINES WITH TRUNK PISTONS

5. General Features.—A vertical six-cylinder marine Diesel engine operating on the four-cycle principle is shown in Fig. 1. It is operated at the high speed of 225 revolutions per minute, which renders it suitable for ship propulsion as well as for general power purposes, as, for instance, the running of an electric generator. The engine is of the so-called trunk-piston type. In order to distribute the severe side thrust on the piston over as large an area as possible, a piston of this type is built extra long, as it actually performs the functions of a crosshead. The cylinders have a bore of $16\frac{1}{2}$ inches and a stroke of 24 inches, and develop about 110 horsepower each. Air is admitted to the cylinders through the mufflers *a* and the exhaust gases from the cylinders are expelled through the common exhaust manifold *b*. All the valves are operated by cams on the cam-shaft, enclosed in the casing *c*. The cam-shaft is mounted level with the cylinder heads and is driven from the crank-shaft through a train of gears located at the middle of the engine. Inspection of the gear transmission system may be made after removing the handhole cover *d* and the cover-plate *e*. Access to the connecting-rod bearings is obtained by removing the handhole covers *f* and the cover-plates *g*. The box frame *h* is supported by the subbase *i*, which is carried by the base *j*. Both base and subbase castings consist of sections bolted together and reinforced by ribs.

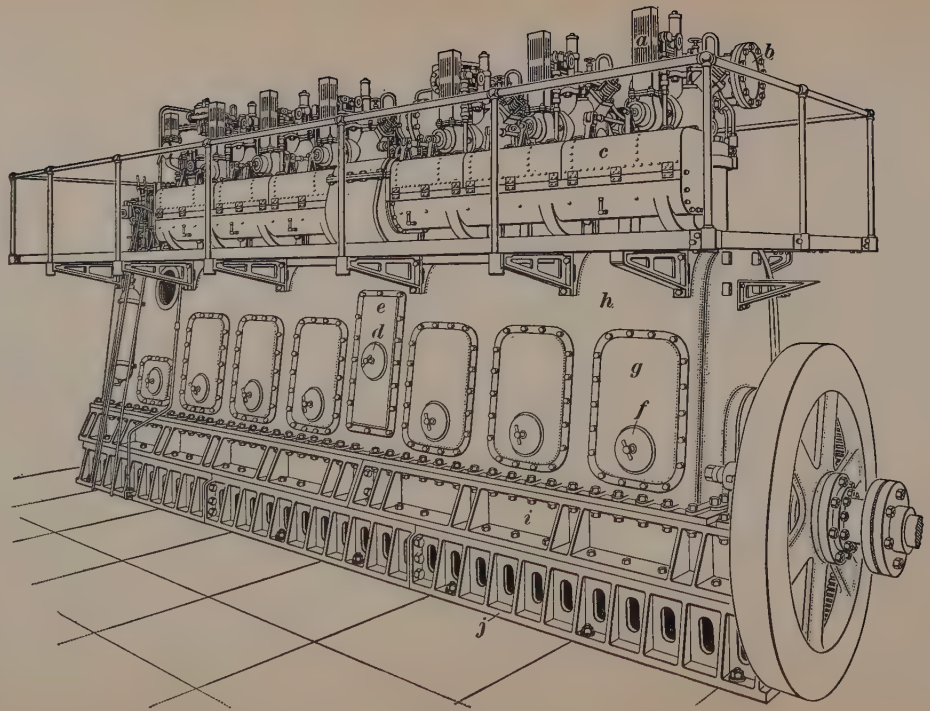


FIG. 1

6. A sectional view of the extreme forward portion of the engine shown in Fig. 1 is given in Fig. 2, including one of the working cylinders *a*, the air compressor *b*, the fuel pump *c*, and the governor *d*. The engine frame *e* is bolted to the bed-plate, or base, at the bottom and extends to the top of the working cylinders. The base is strengthened by cross-girders *f* that support the crank-shaft bearings. To the top of the frames are bolted the cylinder heads *g*, which contain the air-starting valves *h*, the fuel valves *i*, and the air-inlet and exhaust valves, not shown. The wall *j* between the cylinder *a* and the air compressor *b* makes it possible to use different lubricating oils in the compressor and in the engine crank-case. On the forward end of the engine, in front of the fuel-pump governor, is the operator's station with the controls for starting and stopping the engine. The three-stage air compressor *b* is driven from the crank-shaft by a connecting-rod *k* through the crosshead *l* and the piston rod *m*.

7. The governor spindle *n*, Fig. 2, is driven from the crank-shaft through the bevel gears *o* and *p* and carries the spider *q* to which the governor weights *r* are attached. These weights are mounted on a horizontal rod *s*, and when the speed of the engine increases, they are thrown outwards by centrifugal force against the resistance of the springs *t*. The outward movement of the weights is transmitted, through bell-crank levers *u* pivoted at *v*, to a sleeve *w* on the spindle, causing it to be raised. The movement of the sleeve in turn is transmitted to the by-pass valve of the fuel pump, causing a smaller amount of fuel to be delivered to the cylinders, thus reducing the power developed and consequently the speed.

Lubrication is accomplished by a gravity-feed tank supplying oil under pressure to the main bearings, thence through passages *x* drilled in the crank-shaft journals and cheeks, to the crankpin bearings, and finally through the passages *y* in the connecting-rods to the piston pins. The surplus oil is led to the crank-case, strained and pumped back to the tank. Lubrication of the cam-shaft is effected by the splash system, the oil being contained in the closed cam-shaft casing.

8. Method of Operation.—A sectional view of one of the working cylinders of the engine in Fig. 1, taken at right angles to the crank-shaft, is shown in Fig. 3 Air at atmospheric pressure enters the cylinder on the suction stroke through the slotted muffler z and the intake valve a_1, all other valves being closed. On the return stroke, or compression stroke, the intake valve also is closed and the air in the cylinder is compressed to about 500 pounds per square inch. Just before the piston reaches the top of its stroke the fuel valve i opens and admits the fuel charge, which is forced into the cylinder against the compression pressure by the injection air. The temperature of the compressed air in the cylinder is sufficient to ignite the vaporized fuel and the piston is driven downwards on its working, or expansion, stroke by the pressure of the gases of combustion. The fuel valve closes after the piston has traveled about 10 per cent. of its working stroke. The fourth, or exhaust, stroke of the piston expels the burned gases through the exhaust valve b_1 into the water-cooled manifold c_1, thus completing the cycle.

9. Cylinder.—The cylinder barrel a, Fig. 3, consists of a liner pressed into a housing e that forms the upper end of the frame. A short flange at the upper end of the liner fits snugly into a recess formed in the housing at d_1; thus, when the cylinder head is bolted fast, the liner is held firmly in place. Because it is subjected to the heat of combustion, the liner will expand considerably more than the housing, and so provision must be made to allow free lengthwise expansion. Shoulders e_1 and f_1 are formed on the housing and are machined to make contact with similar machined faces on the liner. Thus, the liner is free to expand downwards and at the same time is held laterally. The space g_1 between the liner and the housing forms the water-jacket, and leakage at the bottom is prevented by a rubber packing ring h_1. As the liner is separate from the housing, it may be replaced cheaply when worn; also, it may be made of hard, close-grained cast iron and the housing of softer iron. These advantages would not be obtained if the liner and the housing were cast in one piece.

10. Cylinder Head.—The cylinder head g, Fig. 3, is bolted to the top of the housing e and contains the air-inlet valve a_1, the fuel valve i, the exhaust valve b_1, and the air starting valves, not shown, all actuated by cams on the horizontal cam-shaft i_1. The horizontal position of the air-intake and exhaust valves is responsible for the location of the combustion chamber j_1 in the cylinder head instead of its being located, as in most Diesel engines, between a flat cylinder head and a flat piston. The advantage of having the combustion space in the cylinder head is that it reduces the cooling effect produced by the entering injection air. This cooling often causes cracked pistons and delays combustion of the fuel charge by decreasing the temperature of the compressed air in the cylinder.

11. Valve Motion.—All the valves of the engine are operated from the cam-shaft i_1, Fig. 3, through rocker-arms. The air-intake valve a_1 is opened by the action of the cam k_1, which is in contact with a roller l_1 at one end of a rocker-arm m_1 fulcrumed at n_1. The valve is opened against the pressure of the spring o_1 and is then returned to its seat by the action of the spring.

The cam-shaft, shown at i_1, Fig. 4, is mounted in front of the cylinders, near the top of the engine, and is driven through a train of spur gears p_1 from the pinion q_1 on the crank-shaft r_1. The gearing through which the cam-shaft is driven is located at the center of the engine, between the middle cylinders. Lubrication of the cam-shaft and the cams is effected by the splash system, the lubricating oil being contained in the casing s_1 that encloses the cam-shaft.

12. Compressor.—A three-stage air compressor, shown in vertical section in Fig. 5, furnishes compressed air for starting the engine and for the injection of the fuel. The compressor cylinders are arranged in a vertical line above the crank-shaft r_1 and the three pistons t_1, u_1, and v_1 are rigidly connected, so that they move in unison. The low-pressure piston u_1 is located between the intermediate-pressure piston t_1 at the bottom and the high-pressure piston v_1 at the top. The

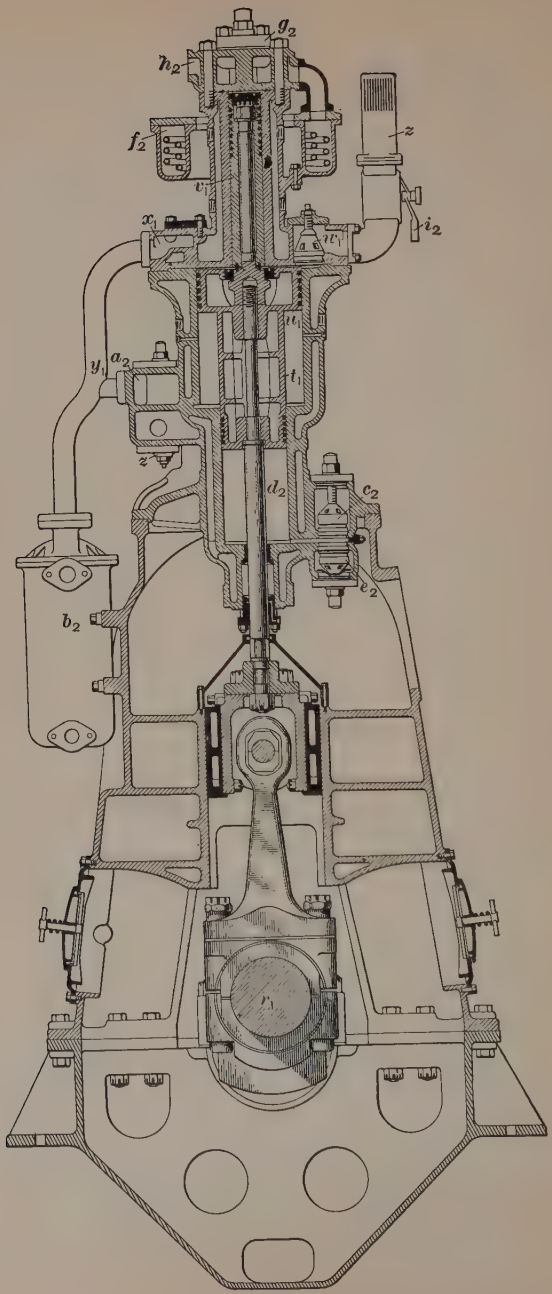


FIG. 5

low-pressure piston is double-acting, whereas the other two are single-acting. On the downward stroke, air is drawn into the low-pressure cylinder above the piston through the slotted intake z and the suction valve w_1. On the succeeding upward stroke, this air is compressed and discharged through a valve at x_1 into the pipe y_1, while, at the same time, air is drawn into the cylinder below the piston through the suction valve z_1. The air below the piston is compressed on the downward stroke and discharged into the pipe y_1 through the valve a_2. The pipe y_1 conveys the compressed air from the low-pressure cylinder to the intercooler b_2.

13. The air leaves the low-pressure stage of the compressor, Fig. 5, at a pressure of about 80 pounds per square inch and is thoroughly cooled in the intercooler b_2. It is then led through the suction valve c_2 into the intermediate cylinder d_2, in which it is compressed on the downward stroke of the piston t_1 to a pressure of about 250 pounds, and discharged through the valve e_2 into a second intercooler f_2. By passing the highly heated compressed air through the coils of the intercooler f_2, around which water circulates, the air is made to give up a large part of its heat. During the cooling, a large part of the moisture in the air condenses; this moisture, together with excess lubricating oil carried by the air from the compressor cylinders, is drained off at regular intervals. The air is then passed through a valve at g_2 into the high-pressure cylinder, where it is compressed on the upward stroke of the piston v_1 to a pressure of from 800 to 1,000 pounds per square inch, and is finally discharged through a valve at h_2. The final pressure of the high-pressure air may be varied to suit the load conditions of the engine by regulating the volume of air entering the compressor at z, which is accomplished by hand manipulation of a throttle controlled by the handle i_2. Often the high-pressure air is cooled in an *aftercooler* before it enters the fuel valve. The aftercooler may be the water-jacket of the high-pressure cylinder itself, into which are led the coils through which the air circulates; or it may be built as a separate tank.

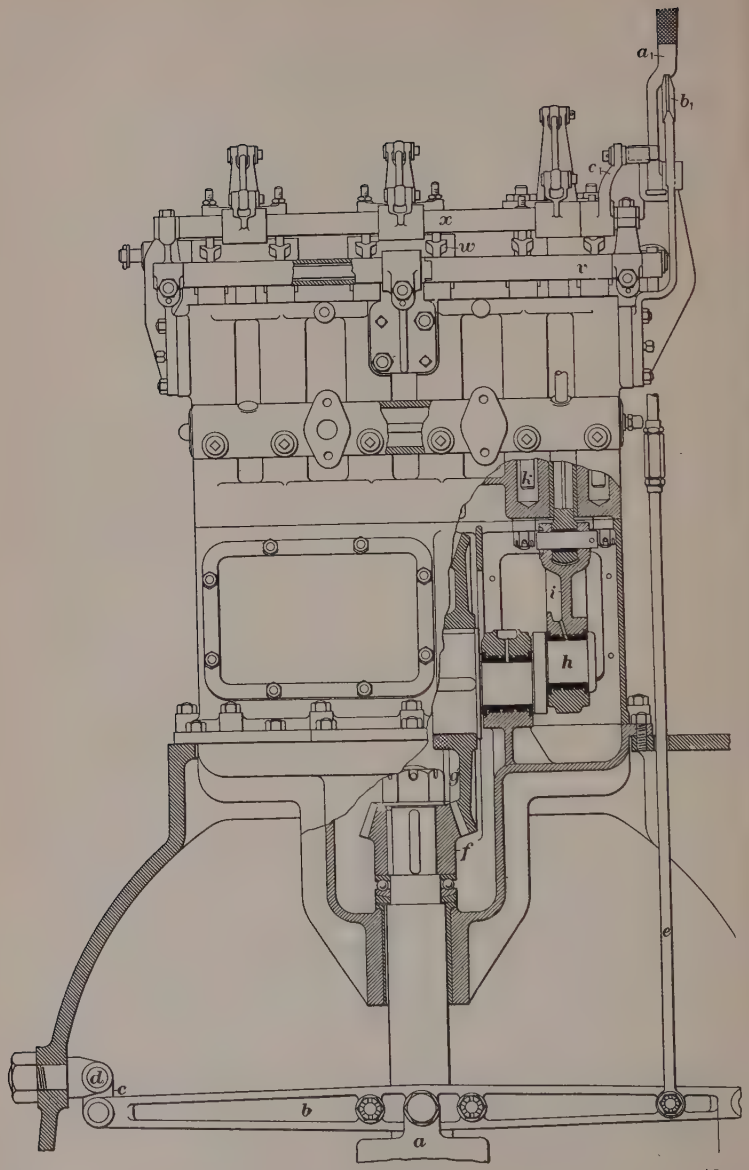


FIG. 6

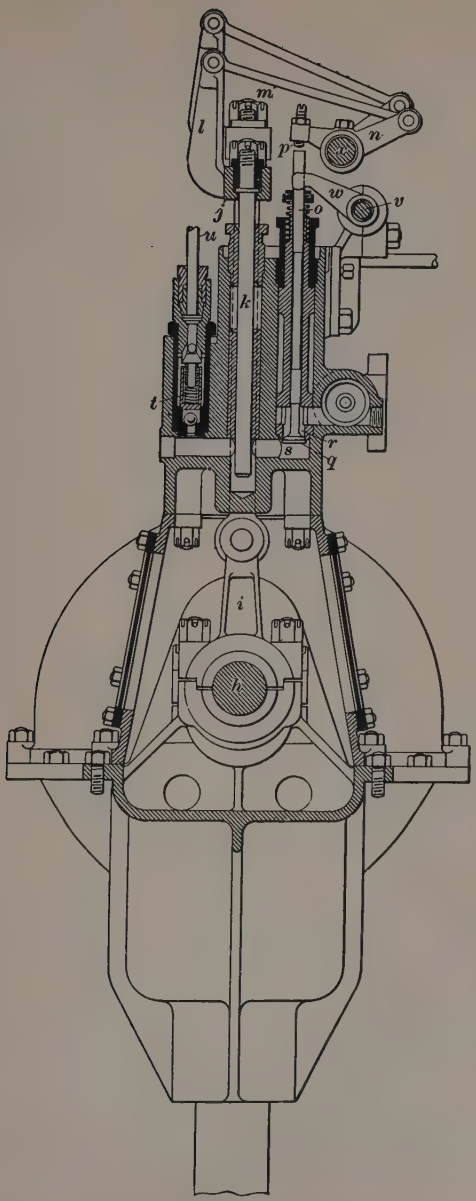


FIG. 7

14. Fuel Pump.—The fuel pump is shown in Figs. 6 and 7, corresponding parts in both illustrations having the same reference letters. The movable sleeve *w*, Fig. 2, is shown at *a*, Fig. 6, connected to a lever *b* that is joined by a short link *c* to the stationary pivot *d*. Thus, when an increase of engine speed raises the sleeve *a*, the lever *b* is swung upwards, carrying with it the control rod *e* by which the quantity of fuel delivered by the pump is regulated. The pump is driven from the governor spindle through a bevel pinion *f* that meshes with a gear *g* on the shaft that carries the eccentric *h*. On this shaft are fastened the eccentric straps *i*, Fig. 7, of which there is one for each pair of pump plungers. Each eccentric strap is connected to a vertical rod that carries at its upper end a cross-beam *j* rigidly connected to a pair of fuel-pump plungers *k*. This cross-beam is further connected by a bracket *l* and a link *m* to a bell-crank lever *n* that operates the intake-valve plungers *o* through the adjustable screws *p*, sometimes called the hammers. When the intake valve *q* opens, the fuel is admitted by gravity from the oil chamber *r* to the space *s*, from which it is forced through the discharge valve *t* and pipe *u* to the fuel valve on the discharge stroke of the fuel-pump plunger *k*.

15. Speed Control.—When the governor weights change position because of a change of speed, their movement is communicated to the rod *e*, Fig. 6, which is connected to the shaft *v*, Figs. 6 and 7, held in eccentric bearings. The turning of this shaft alters the position of the fingers *w*, which act on the intake-valve plungers of the fuel pump, and thus varies the period of opening of the intake valve during the discharge stroke of the plunger. In this way, the quantity of fuel delivered, and consequently the power developed, is regulated, resulting in regulation of the speed of the engine. The speed may also be regulated by hand. The shaft *x* has eccentric bearings, and, to vary the quantity of fuel delivered, and therefore the speed, the shaft is turned slightly by means of a handle a_1, that moves over the quadrant b_1, and the arm c_1, thus raising or lowering the arm *n*, Fig. 7, and the hammer *p*, and so changing the period of opening of the fuel valve.

16. High-Speed Marine Diesel Engine.—A sectional view of one of the cylinders of a smaller type of four-cycle high-speed marine Diesel engine, embodying features similar to those of the larger engine just described, but differing mainly in the construction of the cylinder head, is shown in Fig. 8. The cylinders are 9 inches in diameter, and the stroke is $12\frac{1}{2}$ inches, each cylinder developing 30 horsepower at 350 revolutions per minute. The engine is built as a multicylinder unit with four, six, or eight cylinders, developing 120, 180, or 240 brake horsepower, respectively. Each working cylinder is cast separately, the water-jacket, cylinder head, and liner all being cast in one piece. On the front of the engine the inlet valve *a*, and the air starting valve, not shown, are actuated by rocker-arms such as that shown at *b*, pivoted on the brackets *c*, while at the back of the engine the exhaust-valve rocker-arms *d* are located. The two cam-shafts *e* and *f* that carry the cams for operating the rocker-arms are supported by bearings bolted on top of the housing *g*, and each is driven by two-to-one reducing gears from the crank-shaft. Adjustment of the clearances of the rollers at the ends of the rocker-arms may be made by means of the setscrews *h* at the other ends of the arms. The cam-shaft *e* on the front of the engine also actuates the fuel valve *i* by means of rocker-arms and the bell-crank lever *j*. The connecting-rod *k* at the wristpin end is solid and is fitted with removable bushings.

17. A two-stage air compressor, driven from the crank-shaft and located adjacent to the cylinder nearest the flywheel, furnishes air for starting and for fuel injection in the engine shown in Fig. 8. The starting air is supplied by the low-pressure stage of the compressor and the injection air by the high-pressure stage. For starting purposes, only half of the cylinders of the engine are equipped with air starting valves. The fuel pump and governor are of the same types as those illustrated in Figs. 2, 6, and 7. They are located at the forward end of the engine, that is, the end away from the flywheel, the pump being driven from the front cam-shaft and equipped with a separate plunger for each cylinder. The

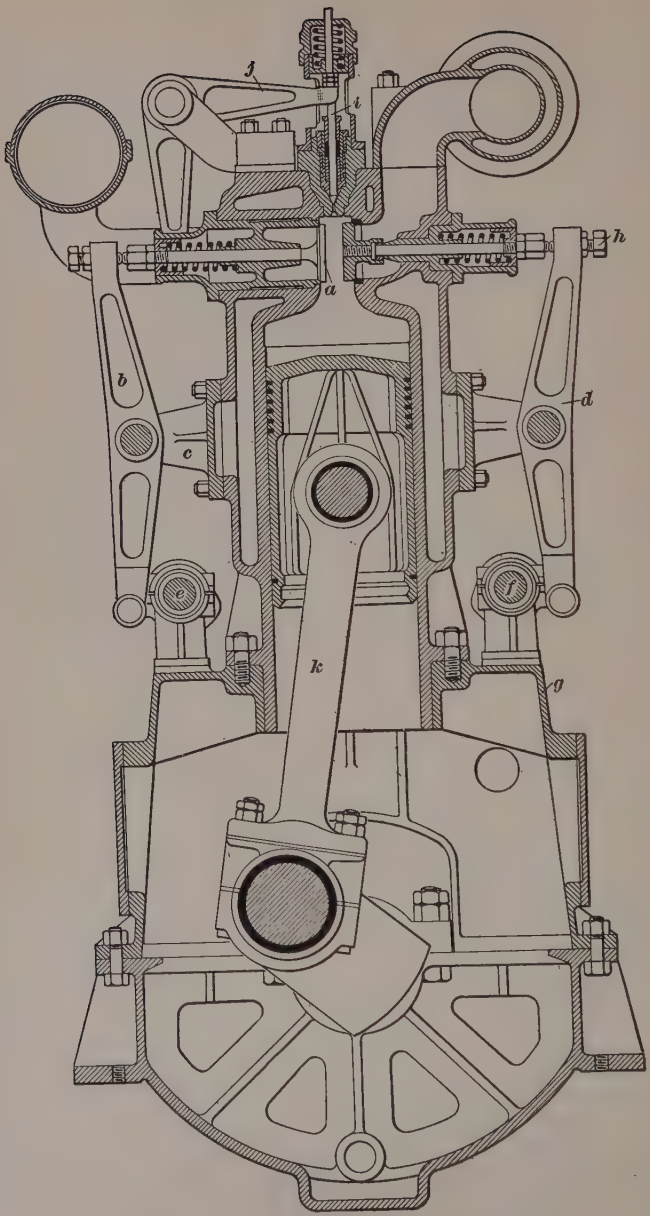


FIG. 8

governor controls the speed of the engine by regulating the amount of fuel supplied, the quantity being varied by controlling the timing of each individual suction valve of the fuel pump.

18. Hvid, or Brons, Type of Engine.—The type of engine developed by Hvid and Brons, and therefore known by the names of these men, belongs to the four-cycle class. A sectional view of the cylinder of such an engine is shown in Fig. 9, and Fig. 10 is an enlarged section of the upper end of the cylinder and the fuel valve. There are four valves in the water-jacketed head *a* of the engine. One is the fuel-inlet valve *b*, one is an air-admission valve for starting the engine, and the other two are the air-inlet and the exhaust valve, respectively. On the suction stroke of the piston *c*, which is a downward stroke, the air valve opens and a charge of clean air is drawn into the cylinder. The air valve is opened mechanically by the movement of the rocker-arm *d*, actuated through the rod *e* and the lever *f* from the cam *g* on the cam-shaft *h*. The cam-shaft is driven from the crank-shaft *i* at half the speed of the latter.

19. When the rocker-arm *d*, Figs. 9 and 10, presses the stem of the air-inlet valve down against the action of the spring *j*, it also forces downwards the lever *k*, which is pivoted at *l* and bears on the stem *m* of the valve *n*, and so forces the valve *n* off its seat. When this occurs, fuel oil in the space surrounding the needle valve *o* flows down through the passage *p* and falls into the cup *q*, which has small holes *r* that open out into the upper end of the cylinder. These holes are slightly above the bottom of the cup and are of small diameter, so there is no danger that the partial vacuum produced in the cylinder during the suction stroke will draw the fuel through the cup orifices into the cylinder. As soon as the piston finishes the suction stroke and starts on the return, the air-inlet valve closes and the fuel valve likewise. The cylinder then is filled with air and the cup *q* contains a charge of fuel.

20. On the upward stroke of the piston, which is the compression stroke of the cycle, the air is compressed into the

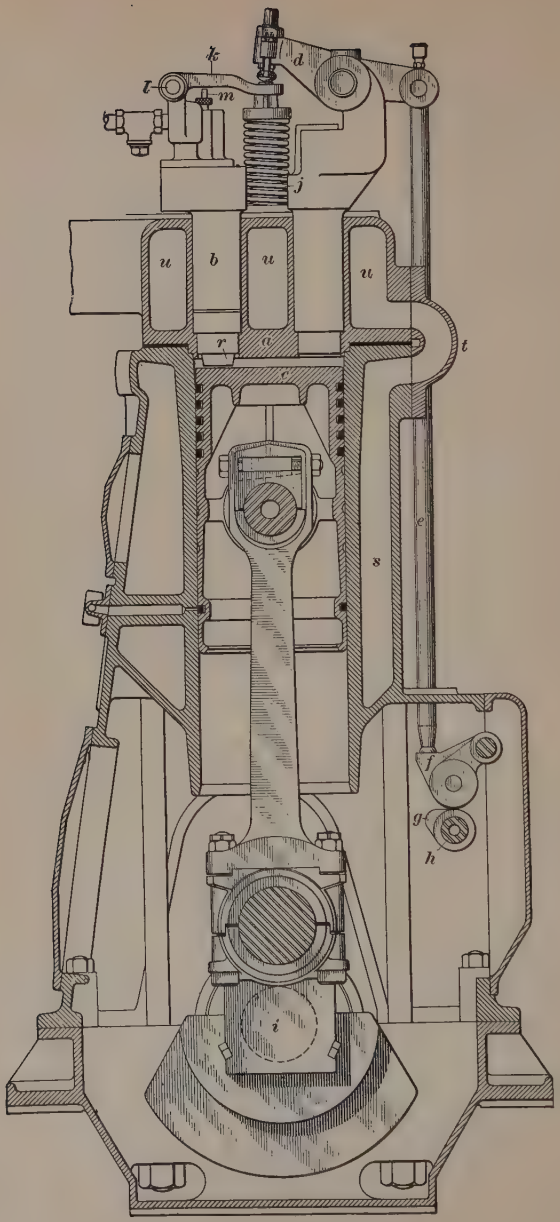


FIG. 9

small space at the upper end of the cylinder and its pressure is increased to from 380 to 450 pounds per square inch, depending on the grade of fuel used. The temperature of the air under this compression is correspondingly raised to a high point. As the interior of the cup *q*, Fig. 10, is in communication with the cylinder through the holes *r*, the pressure and temperature of the air in the cup also rise, and the heat thus developed vaporizes some of the lighter parts of the oil in the cup. This oil vapor, mixing with the highly heated air in the cup, ignites and burns and the combustion causes a sudden increase of pressure inside the cup, the pressure developed being much higher than that in the cylinder. As a consequence, there is a rapid escape of gases outwards through the holes *r*, carrying with them the oil remaining in the cup, and the oil is thus heated and sprayed out into the hot air in the cylinder, where it takes fire and burns. The resulting pressure drives the piston downwards on its third stroke, or working stroke.

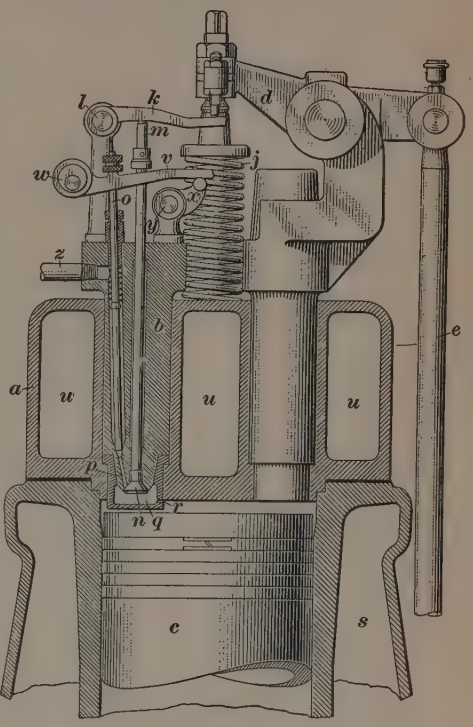


FIG. 10

21. Near the end of the working stroke the exhaust valve is opened and the gases escape into the exhaust pipe. The exhaust valve is operated through the action of a rocker-arm and a push rod from a cam on the cam-shaft, in exactly the

same way as the air valve. On the next upward stroke of the piston, which is the fourth stroke of the cycle, the gases are expelled from the cylinder. The same cycle of events is then repeated in the order already described. The cylinder is surrounded by a water-jacket *s*, Fig. 9, to which cooling water is forced by a pump driven from the crank-shaft. The water from the jacket *s* is led by the fitting *t* to the water-jacket *u* surrounding the valve cages in the cylinder head, from which it escapes through a valve that may be regulated by hand. In this way the temperature of the water coming from each cylinder may be controlled.

22. The speed of the engine in Fig. 10 is controlled by regulating the position of the needle valve *o* and so governing the quantity of fuel admitted to the cup *q* at each suction stroke. The distance that the needle valve is lifted from its seat, and consequently the rate at which oil will flow into the cup, depends on the position of the lever *v*. This lever is fulcrumed on an eccentric *w* at one end and at the other end rests on a lever *x*. The lever *x* is fastened to a shaft *y* that is under the control of a centrifugal governor geared directly to the crank-shaft. When the engine speed increases, the outward movement of the governor weights moves a rod that turns the shaft *y* and lowers the end of the lever *x* slightly. This action lowers the lever *v* and brings the needle valve closer to its seat and so cuts down the amount of fuel. The eccentric *w* may be turned by hand so as to lower the lever *v* and the needle valve, thus reducing the speed of the engine while it is running. The fuel oil is supplied to the fuel valve through the pipe *z*.

23. The governor of the engine shown in Fig. 9 is illustrated by the sectional view, Fig. 11. The governor consists of two weights *a* made in the form of bell-crank levers and pivoted at *b* to a bracket *c* that rotates with the shaft *d*, which is driven from the crank-shaft *e* of the engine through the spiral gears *f* and *g*. The arms *h* of the governor weights carry pins that fit in a grooved collar *i* formed in one end of the sleeve *j*. The other end of this sleeve has a similar groove into which fits a pin *k* on one arm of the bell-crank lever *l*. This lever is ful-

crumed on a stationary pin m and its other arm is connected to a rod n that leads to a crank fastened to the shaft y, Fig. 10. When the speed of the engine increases, the weights a, Fig. 11, are thrown outwards, overcoming the tension of the springs o, and the sleeve j is moved to the left. This motion is transmitted to the shaft y, Fig. 10, causing it to turn and lower the

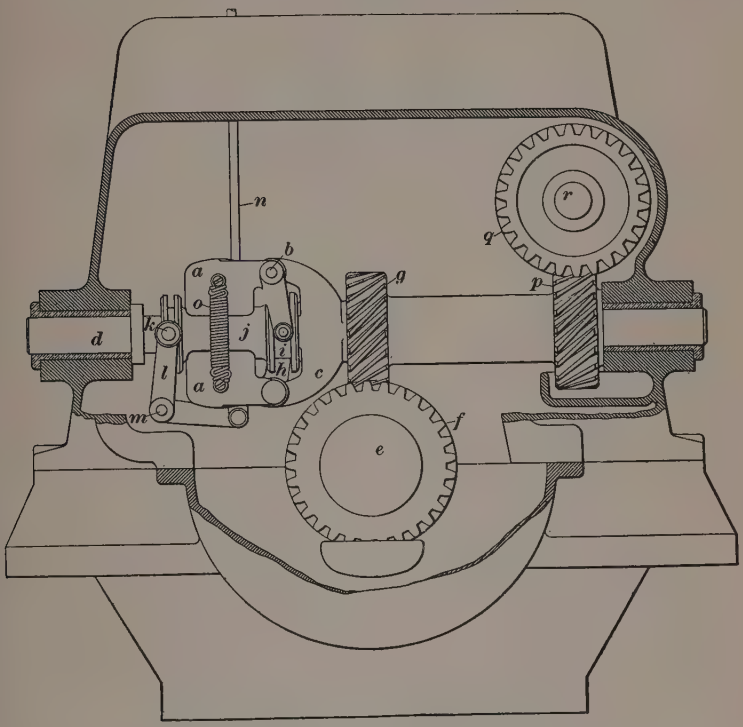


FIG. 11

end of the lever x, thus lowering the needle valve o, decreasing the fuel admitted, and so reducing the speed of the engine. The gear p, Fig. 11, is cut on the same sleeve with the gear g and drives the spiral gear q on the cam-shaft r.

24. The air compressor used on the engine in Fig. 9 is shown in section in Fig. 12. An eccentric a on the crank-shaft b gives a reciprocating motion to the piston c of the air

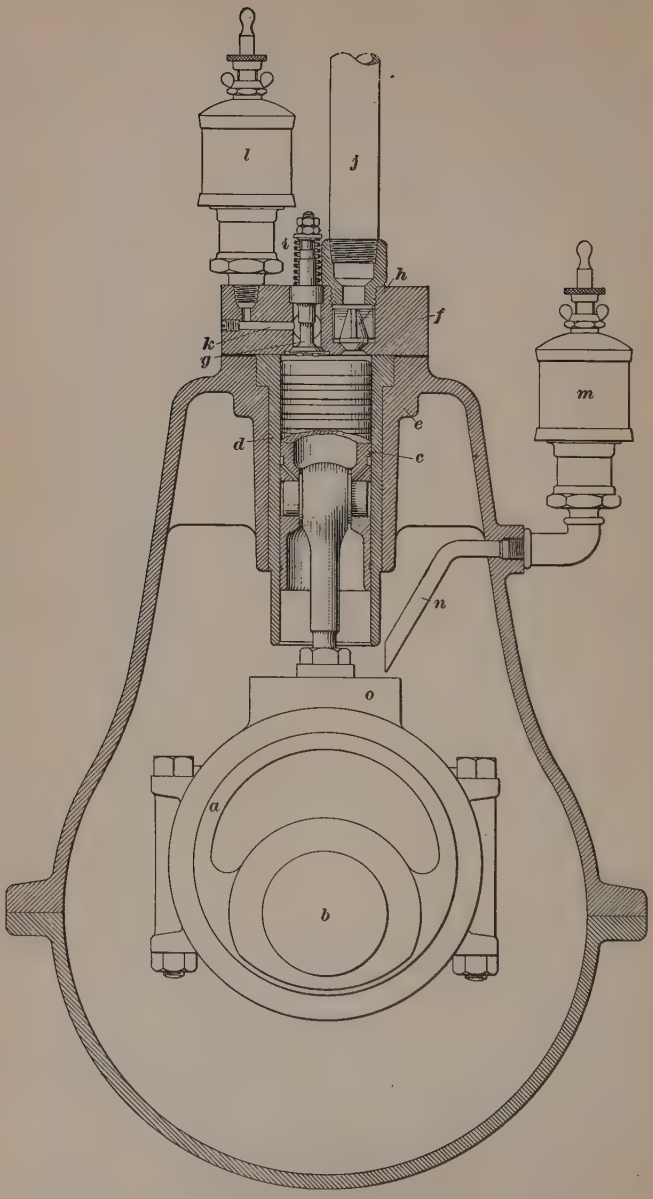


Fig 12

compressor. This piston, which is shown at right angles to its true position, works in a liner *d* held in the frame *e* by bolts passing through the head *f* that contains the inlet valve *g* and the discharge valve *h*. The inlet valve is opened on the downward stroke of the piston by the partial vacuum in the cylinder and is closed at the end of the suction stroke by the light spring *i*. The discharge valve is opened by the pressure in the compressor cylinder and is closed by the pressure in the discharge pipe *j* and the air-storage reservoir to which it is connected. Oil for lubricating the piston and cylinder is admitted through the passage *k* from the sight-feed cup *l* and a cup *m* supplies oil through the pipe *n* to a cup *o* in the upper half of the eccentric strap, from which a hole drilled through the strap leads the oil to the eccentric. The compressor is used to store starting air at a pressure of about 300 pounds per square inch.

CROSSHEAD TYPE OF ENGINE

25. Main Features.—The application of the crosshead type of piston in place of the trunk type of piston is becoming more general, especially in marine practice involving heavy-duty work, because a trunk piston would require a very long cylinder. Although the crosshead design may increase the initial cost to some extent, the diminished wear and consequent longer life of all parts subject to wear compensate for the additional cost. Heating of the wristpin and the pin brasses, so often experienced in the trunk design, is eliminated in the crosshead design, and there is little danger that lubricating oil from the crank-case will be thrown into the cylinder to mix with the fuel oil, as an oil guard may be placed at the crank end of the cylinder to prevent this. On the other hand, the crosshead shoes must be kept accurately adjusted, as a loose crosshead may cause the piston to bind in the cylinder.

26. General Construction.—A front view of a six-cylinder four-cycle Diesel engine having a crosshead type of piston is shown in Fig. 13. The base *a* is a heavy casting made in two

sections, which are bolted together at the middle. Heavy ribs run transversely, forming girders that support the crank-shaft bearings. The frames of the engine are of the box type, and the cylinders are bolted separately to the tops of the frames instead of being cast integral with the individual frames as in some types of **A**-frame engines. By having the cylinders cast separate from the frames, a fractured cylinder may be replaced without replacing a frame at the same time. The frames are bolted to the base and are joined by ribs *b*. In the front of each frame, opposite the crank, is a large opening closed by a removable sheet-metal cover *c*, so that easy access to the crank-case may be had for adjustment of the bearings, crank-shaft, and connecting-rod. A handhole in the center of each cover enables inspection of the working parts to be made readily.

27. In the engine shown in Fig. 13, the cam-shaft *d* is driven from the crank-shaft through a train of spur gears inside the casing *e*. Motion is communicated to the valves by the push rods *f*. The reversing mechanism is located inside the casing *g*, at the same end of the engine as the governor *h* and the fuel pump *i*. The top of the air compressor is shown at *j*, and beside it the cylinder *k* of the regulator by which the discharge pressure of the air from the compressor may be controlled. The force-feed lubricator *l* is driven from the cam-shaft through the shaft *m* and supplies oil to the cylinders, crosshead pins, and air compressor. Lubricant for the main bearings and crank pins is supplied from a pump through the main pipe *n* and branches *o*.

28. Cylinder.—A vertical section through the cylinder of the engine in Fig. 13, parallel to the crank-shaft, is given in Fig. 14. The removable liner *a* is held in the cylinder housing *b*, which is firmly bolted to the top of the box frame of the engine. At the upper end, the liner is secured by bolting on the cylinder head *c*, but at the lower end it is free to expand. The water-jacket *d* is formed between the housing and the liner, and this space may be cleaned by removing the cover-plates from the handholes *e*. The cylinder head is cast

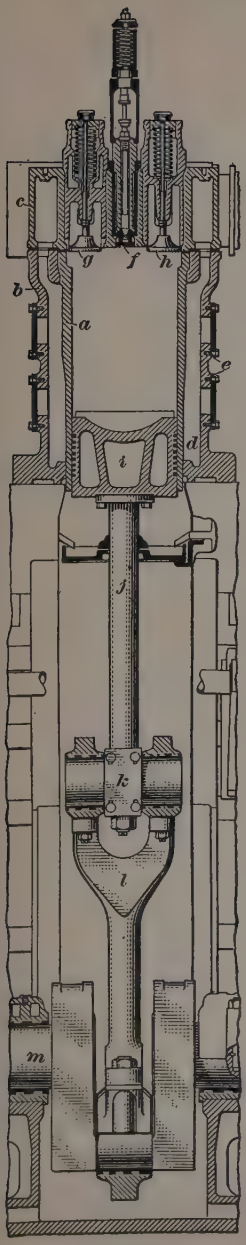


FIG. 14

separately and is bolted in place. It contains openings for four valves; namely, the fuel valve *f*, the exhaust valve *g*, the air-inlet valve *h*, and the air starting valve, not shown. Also, each cylinder carries an automatic relief valve that is simply a spring-loaded safety valve set to open whenever the pressure in the cylinder becomes abnormal. The piston *i* is short and is rigidly bolted to the piston rod *j*, the lower end of which passes through the crosshead *k*. The forked connecting-rod *l* joins the crosshead and the crank-shaft *m*.

29. Piston.—The piston and its attached parts are clearly shown in Fig. 15. The piston *a* is firmly bolted to a flange *b* formed on the upper end of the piston rod *c*, and is cooled by water circulation, the water being led into and away from the piston through telescoping pipes. The pipes *d* and *e* are bolted to the piston and communicate with the water space inside the piston. These pipes slide up and down inside the pipes *f* and *g*, which are stationary and are held by a bracket on the plate *h*. Stuffing-boxes are formed at the upper ends of the pipes *f* and *g*, and any leakage is caught by the tray *i*, which also is provided with a stuffingbox for the piston rod. Thus leakage is prevented from running down into the crank-case. The cooling water enters the pipe *g* through a connection at *j*, then flows up into the piston through the pipe *e*, from which it escapes through the pipes

d and *f*, and is led away through the connection *k* to a suitable outlet.

30. Crosshead.—The piston is short because the side thrust caused by the angularity of the connecting-rod is taken by the crosshead, shown in Fig. 16. The block *a* and the pins *b* and *c* are forged in one piece, which is then bolted to the shoe *d*. This shoe is a steel casting babbitted on both top and bottom, as it slides between guides on the frame. The piston rod passes through the hole *e* in the block and is secured by a nut. It is important that the crosshead be accurately adjusted, so that the piston rod will be

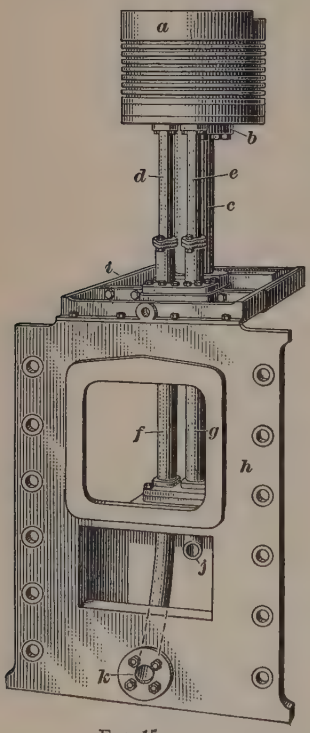


FIG. 15

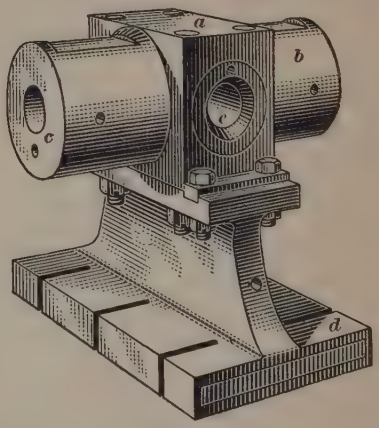


FIG. 16

kept central in the cylinder. As the shoe wears, shims may be inserted between the block *a* and the shoe. When the wear becomes too great to be taken up in this way, the shoe must be rebabbitted.

31. Valves and Valve Gear.—The fuel valve *f*, Fig. 14, is located in the center of the cylinder head, with the exhaust valve *g* and the air-inlet valve *k* on opposite sides of it. These

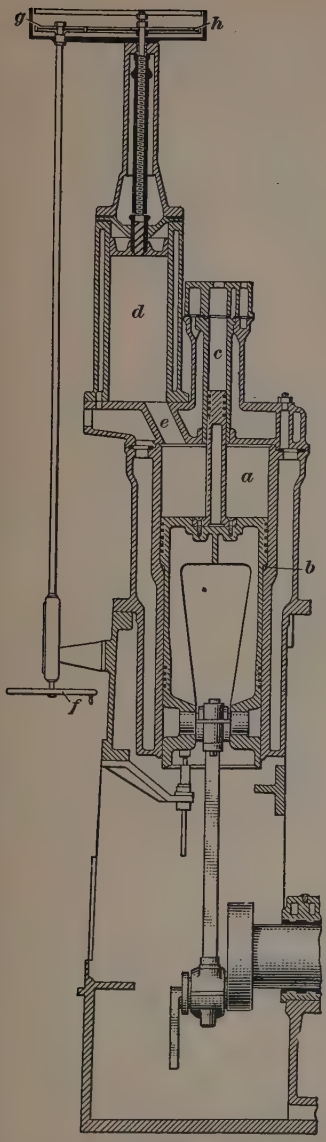


FIG. 17

valves are opened by the action of rocker-arms fulcrumed on brackets attached to the cylinder heads, and are closed by springs. The rocker-arms receive their motion from push rods located vertically on one side of the engine cylinders and actuated by cams on a longitudinal cam-shaft driven by spur gearing from the after end of the crank-shaft.

The cam-shaft is so arranged that it can be shifted endwise, or fore and aft, by turning a hand wheel. This construction is necessary in order to enable the engine to be reversed. At starting, the relief valves on the cylinders may be opened, so as to relieve compression.

32. Air Compressor.—On the compression stroke, air is compressed in the engine cylinders to a pressure of about 500 pounds per square inch and the fuel is injected under a pressure of approximately 850 pounds per square inch. The air for injecting the fuel is compressed by a three-stage air compressor, shown in vertical section in Fig. 17, located at the forward end of the engine and fitted with intercoolers and an aftercooler. It is driven direct from the crank-shaft of the engine and consists of a low-pressure cylinder *a* and an intermediate-pressure cylinder *b*, cast together as shown, and a high-pressure cylinder *c* cast

integral with the low-pressure cylinder head. The air in the low-pressure cylinder *a* and in the high-pressure cylinder *c* is compressed during the upward stroke of the piston, and the air in the intermediate cylinder *b* during the downward stroke.

In operation the compressor does not differ from the ordinary type of three-stage compressor except in the manner of regulating the final air pressure according to the load on the engine. This is accomplished by means of a regulator cylinder *d* that is in direct communication with the low-pressure cylinder *a* through a passage *e*. By turning a hand wheel *f* the pinion *g* may be made to turn the gear *h* which, in turn, lowers or raises the piston in the regulator cylinder *d*. In this way the volume of air compressed in the low-pressure cylinder may be changed to give any desired final discharge pressure.

33. Fuel Pump and Governor.—Views of the fuel pump are shown in Fig. 18. The driving shaft *a* of the pump receives its motion from the cam-shaft through the gear *b*. It carries six eccentrics *c*, one for each cylinder, and these eccentrics are made with faces inclined to the shaft instead of parallel to it. An eccentric strap *d* on each eccentric is connected to a pump plunger *e* that works in a chamber *f* between the suction valve *g* and the discharge valve *h*. A fuel line is led from each discharge valve to one of the engine cylinders and the speed of the engine is regulated by altering the quantity of fuel entering the cylinders.

34. The pump shaft *a*, Fig. 18, is under hand control by means of a hand wheel, so that the shaft may be moved endwise as the speed changes. Because of the inclined positions of the eccentrics, endwise motion of the shaft to which they are keyed will alter their throw, since the eccentric straps do not shift with the eccentrics. When the shaft is in one extreme position, all of the eccentrics run central with the shaft and give no stroke to the plungers. When the shaft is in the other extreme position, the eccentrics have a maximum throw and the plungers have a stroke corresponding to the maximum delivery of fuel desired. Thus, by the simple device of

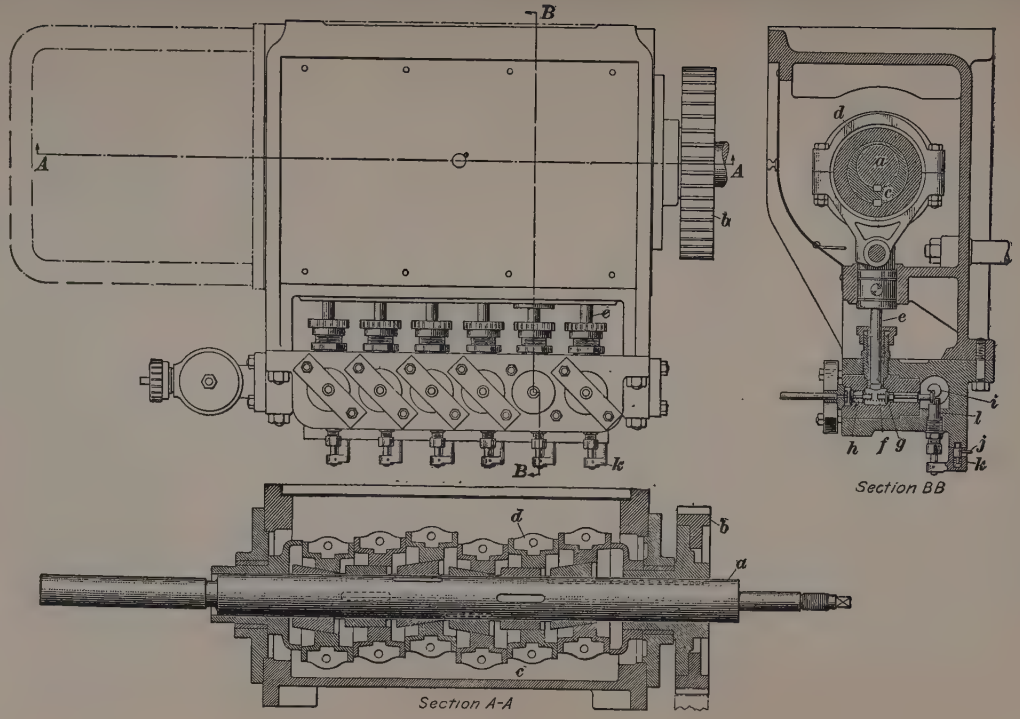


FIG. 18

moving the driving shaft, the strokes of the fuel pumps may be varied between zero and the maximum possible and so the fuel charges can be regulated.

35. A shaft *i*, Fig. 18, with one-fourth of it cut away opposite the stem of each suction valve, extends through the pump casting from end to end, below the suction valves, and is connected to an overspeed governor of the centrifugal type mounted on an extension of the pump shaft. The governor operates through a linkage and rotates the shaft *i*. The flat surfaces of the cut-away parts of the shaft will then bear against the ends of the suction-valve stems, force the valves off their seats and hold them open, and so no fuel will be discharged to the cylinders.

In case of repair to one of the fuel lines, it is not necessary to stop the engine. The catch *j* is released and the arm *k* is swung to one side, thus turning the short shaft *l*, which has a flat at its inner end. The valve *g* is thus forced off its seat and the delivery of oil by that pump is stopped, thus enabling the fuel line to be repaired. Or, if the engine is drifting, that is, turning over without developing much power, any desired number of cylinders may be put out of action by turning the arms *k* on their fuel pumps.

36. Fuel Valve.—Sectional views of the fuel valve are shown in Fig. 19 (*a*), (*b*), and (*c*). The body *a* is made of cast iron and contains the needle *b* that controls the admission of fuel, the spring *c* that returns it to its seat, and the block *d*, known as a pulverizer or atomizer, the purpose of which is to atomize the fuel. A perspective of this block is shown in (*d*). The lower end of the atomizer is tapered and fits snugly to a similarly tapered seat in the valve body. The needle *b* passes down through the center of the atomizer and is made a sliding fit at the upper end *e*; but from this point the atomizer is cut away with a gradually increasing clearance so as to form an annular chamber *f* around the needle. A number of passages *g* and *h* connect this chamber with the annular chamber *i* outside the atomizer and with the space *j* above it.

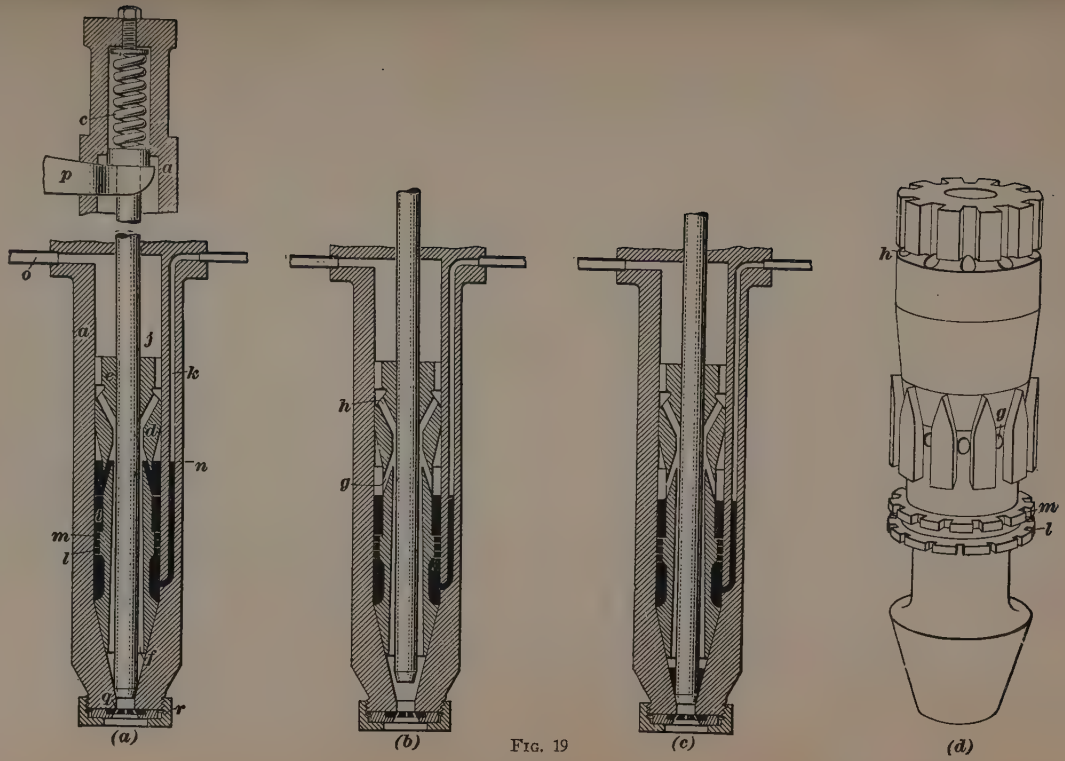
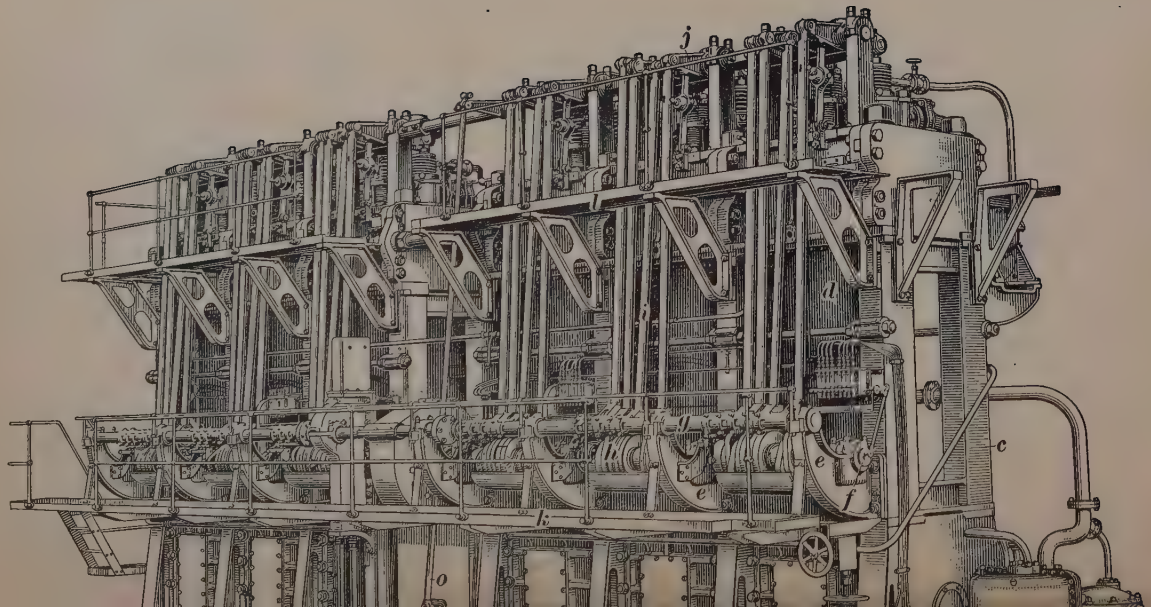


FIG. 19

37. The fuel pump forces a measured quantity of fuel to the fuel valve by way of the passage *k*, Fig. 19 (*a*). This fuel oil flows through the slots in the collars *l* and *m* and rises to about the level *n*. The air for injection of the fuel enters through the passage *o* and fills the space *j* as well as the passages in the atomizer above the level of the fuel. When the needle *b* is raised by the action of the rocker-arm *p*, operated from the cam-shaft, the air flows at high velocity from the space *j* through the ports *h* and the annular chamber *f* into the cylinder. This rush of air past the upper ends of the passages *g* creates a suction effect on the fuel oil in those passages, with the result that the oil is drawn up out of the passages into the upper end of the chamber *f*, where it is caught by the swiftly moving air-current and carried into the cylinder. At the lower end of the fuel valve is a distributing plate *q* held in place by a cap *r*, the purpose of which is to throw out the oil in a conical spray.

38. During the period in which the needle *b*, Fig. 19 (*a*), is raised, fuel oil is drawn out of the passages *g* until the level of the oil falls to the lower ends of these passages, at which time the needle returns to its seat. The oil then stands as shown in (*b*). When the needle valve closes, a small amount of oil is trapped in the chamber *f*, above the valve seat, as indicated in (*c*). At the next opening of the needle valve for admission of fuel, this oil is blown into the cylinder ahead of the injection-air charge and serves to start the ignition of the succeeding fuel charge. This early ignition serves to offset the chilling effect produced by the expansion of the injection air.

39. Lubrication.—The oil for the main bearings and the crankpins is supplied through a main header and branch pipes at a pressure of about 10 pounds per square inch. The oil is led to an annular groove in each main bearing. Radial holes in the crank-shaft conduct some of the oil to a passage in the center of the crank-shaft and thence the oil flows through passages in the cranks to the crankpins. At each crankpin the oil is discharged into an annular groove in the crankpin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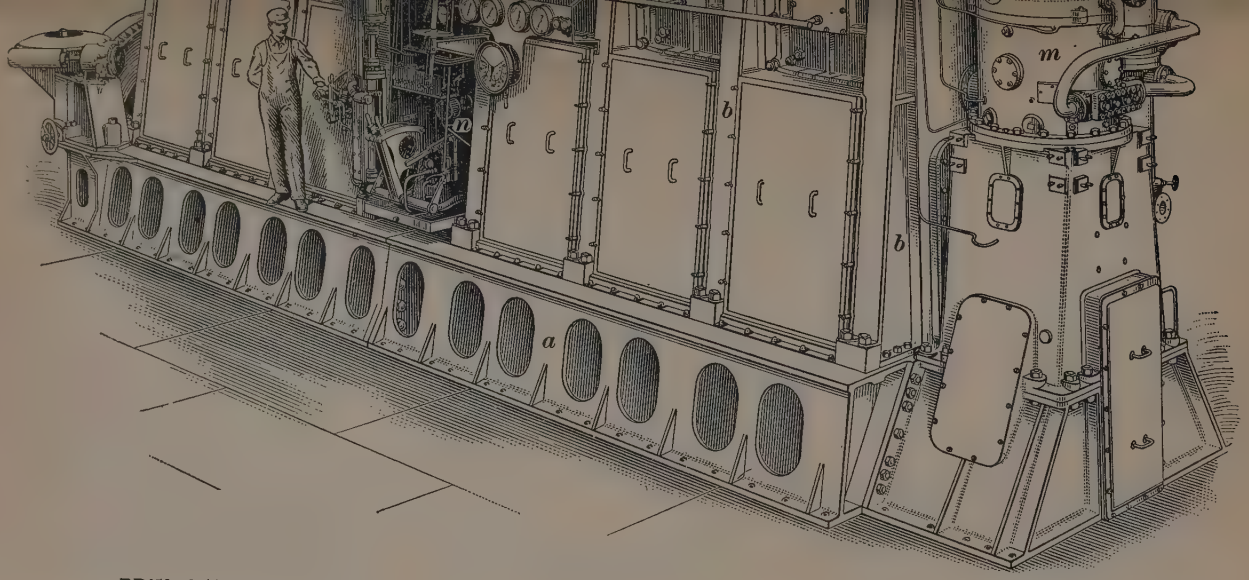

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FIG. 20

brasses. A hole drilled in the connecting-rod conveys some of the oil to the crosshead, where it escapes through holes in the shoe and lubricates the guides. The base of the engine is closed, forming a sump in which the oil escaping from the working parts collects. A small pump driven from the crank-shaft forces this oil to a filter, and from the filter the oil is returned to the supply tank to be used again.

LARGE FOUR-CYCLE MARINE DIESEL ENGINE

40. General Description.—The engine illustrated in Fig. 20 is of the crosshead type with enclosed crank-case, and operates on the four-cycle principle. It is built in units of six or eight cylinders in each of two forms—a short-stroke engine running at 115 revolutions per minute, and a long-stroke engine operating at 85 revolutions per minute. Both types, when constructed as six-cylinder units, are rated at 2,250 horsepower and both have the same cylinder diameter of $29\frac{1}{8}$ inches. The short-stroke engine has a stroke of $45\frac{1}{4}$ inches and the long-stroke type has a stroke of 59 inches. In many recent installations on vessels of large tonnage the short-stroke engine has been installed in sets of two for twin-screw service. The long-stroke engine is especially adapted to the single-screw ship. The construction of both types is essentially the same, the principal difference being in the support of the cylinders on the frames.

41. In the six-cylinder engine shown in Fig. 20, the heavy cast-iron base *a* is made in two sections bolted together at the middle of the engine. This base supports the **A** frames *b* that carry the stanchions *c* to which the cylinders *d* are bolted. Brackets *e* carry the cam-shaft *f* and the lay shaft *g*, and motion is transmitted from the cams *h* to the valves by the push rods *i* and the rocker-arms *j*. The operating mechanism of the valves is readily accessible from the platforms *k* and *l*. The starting and reversing of the engine are carried out from an operating station at the middle of the engine, near the base. Air for fuel injection and starting is furnished by an air compressor *m* driven by a crank on the end of the main crank-shaft.

42. Frame and Cylinders.—A cross-section of the engine shown in Fig. 20, at right angles to the crank-shaft, is given in Fig. 21. The cylinder *a* is set on the frame *b*, which in turn rests on the base *c*, and all are tied together by heavy rods *d* that extend from the top of the cylinder to the bottom of the base. These rods carry a large part of the tensile stresses set up when the engine is in operation. The cylinder head *e* is of deep section and groups of three heads are bolted together into one block; the two units thus formed are supported on stanchions, as *f*. At the middle of the engine these units are separated by a housing for the gear train that transmits motion from the crank-shaft to the cam-shaft. The cylinder liner *g* is held by a flange at its upper end, and the space *h* between it and the cylinder forms the water-jacket. The liner is left free to expand at the bottom, leakage from the water-jacket being prevented by a rubber ring fitted in a groove in the liner. As the cylinder pressures and temperatures are much more severe at the top of the cylinder than at the bottom, the liner is made thicker at the top and tapers toward the bottom.

43. Piston.—The crank-case is separated from the cylinder by a division plate, or diaphragm *i*, Fig. 21, fitted with a stuffingbox *j* through which the piston rod passes. In this way dirty cylinder oil or unburned fuel oil is prevented from leaking into the crank-case and oil from the crank-case is prevented from passing up into the cylinder. The piston *k*, being of the crosshead type, is made quite short, without the skirt customary with the trunk type of piston. The upper piston ring is purposely placed at a little distance from the top of the piston, away from the intense heat, and is therefore not so liable to stick in its groove. Piston cooling is effected by water forced through a telescoping tube *l* into the piston and overflowing into another similar tube *m* that carries it off to water connections outside the crank-case. The tubes *l* and *m* slide in stuffingboxes *n*. To fit new piston rings, or to examine a cylinder liner, the crankpin of the cylinder involved is put on the lower dead center, and the cylinder head, com-

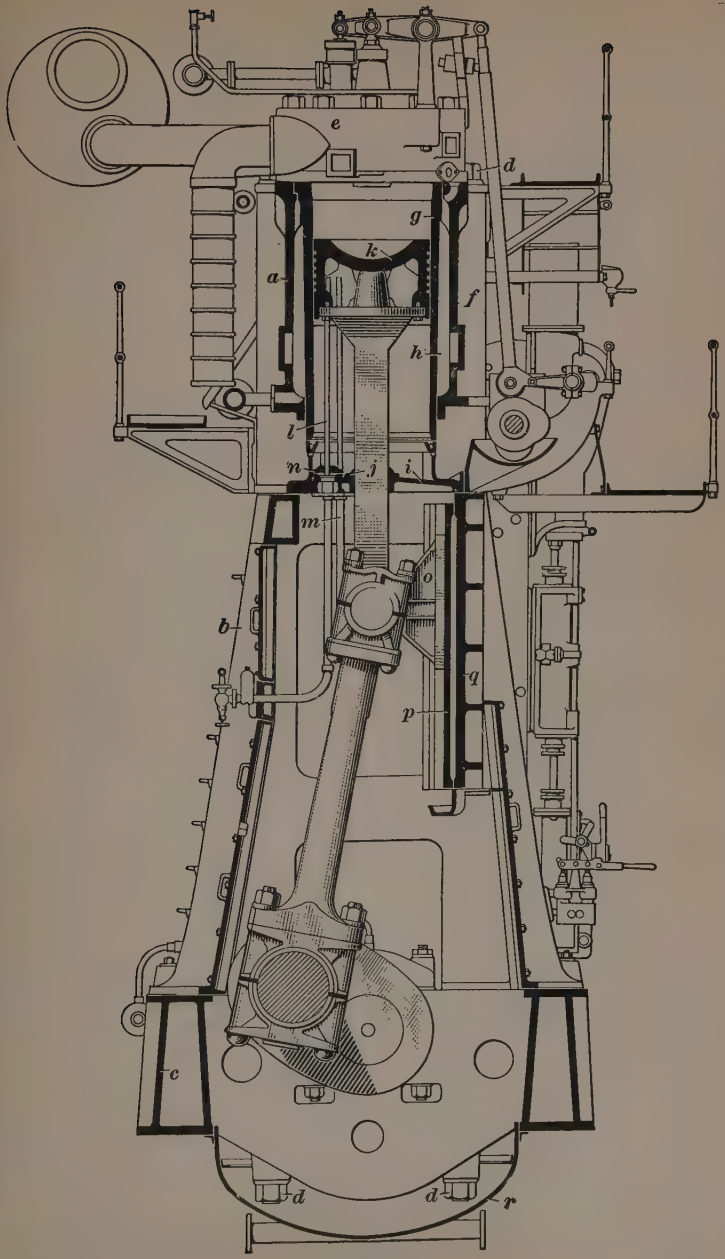

FIG. 21

plete with the liner, is lifted sufficiently to expose the piston.

44. Crosshead and Crank-Shaft.—The crosshead *o*, Fig. 21, is of the single-slipper, or shoe, type with a cast-iron shoe having babbitted bearing faces. The shoe is bolted to the crosshead and slides over the water-cooled guide *p* mounted on the cross-piece *q* fitted between the **A** frames. Any wear on the crosshead shoe is compensated for by placing thin shims under the guide. The piston rod is threaded at its lower end and passes through a squared portion of the crosshead, being locked in place by a nut at the bottom. The forked upper end of the connecting-rod is squared off and bolted to the lower half of the crosshead-pin bearing. Contrary to the usual construction, the engine crank-shaft is built up, the crankpins being shrunk into the webs and the webs shrunk and keyed to the shaft. In this way the two sections of built-up crank-shaft are interchangeable, and the sections are then bolted together. A separate crank on the end of the main crank-shaft drives the three-stage air compressor that furnishes air at 850 pounds pressure for the injection of fuel, and air at a lower pressure for starting purposes.

45. Cylinder Head.—The cylinder head of the engine in Fig. 20 is shown in detail in Fig. 22. It contains the openings for the inlet-valve cage *a*, the exhaust-valve cage *b*, the fuel valve *c*, and the starting valve *d*. Only the exhaust-valve cage is water-cooled, cooling water from the cylinder head entering the cage through the pipe *e* and discharging through the pipe *f*. A thermometer *g*, placed in the outlet pipe, enables the operator to regulate the cooling-water temperature by varying the amount of water by means of the valve *h*. The inlet-air and the exhaust gases pass through the inlet-valve cage and the exhaust-valve cage, respectively, instead of through cored passages in the sides of the cylinder head as in the short-stroke engine of this type. The rocker-arms *i* that operate the valves are pivoted on a common fixed shaft *j* carried on stanchions *k* mounted on the cylinder heads. The

cylinder head is recessed on the inside, forming an approximately spherical cavity that serves as a combustion chamber.

46. Valves and Valve Gear.—The rocker-arms *i*, Fig. 22, by which the valves are operated, are actuated by push rods *l* that receive motion from cams on the cam-shaft. The screw *m* at the end of the rocker-arm may be turned up or down by means of a square-ended wrench, and thus the actual time of

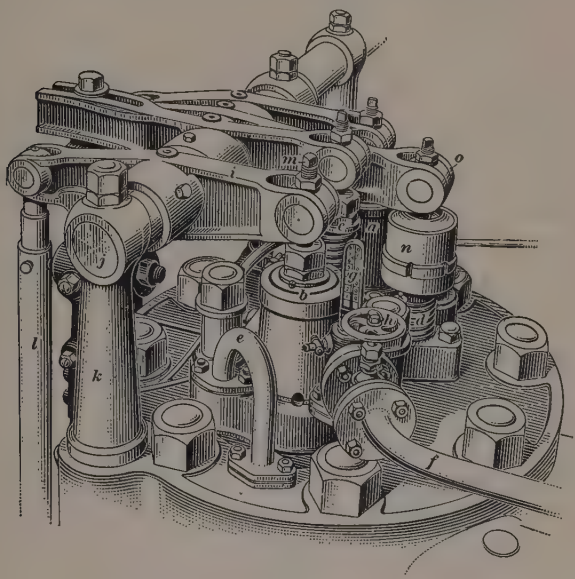

FIG. 22

opening or closing of the valve may be made later or earlier, as desired. The fuel valve *c* differs from that used in most other engines in that it is of the mushroom type and opens inwards. The oil is thus sprayed into the cylinder instead of being directed in a jet against the center of the piston. The air starting valve *d* is operated by a small air cylinder *n* on top of the valve. When compressed air is admitted to this cylinder, the end *o* of the rocker-arm is pushed up and the push rod and its cam roller are forced into contact with the air starting cam on the cam-shaft.

The arrangement of the cams and the lower ends of the push rods is shown in Fig. 23. The cam-shaft *a* carries two sets of adjacent cams *b* and *c*, one for ahead motion and the other for astern motion. Rollers *d* on the lower ends of the push rods *e* rest on the cams, and a swinging link *f* joins each push rod with the lay shaft *g*.

47. Reversing Operation.—When the engine is running ahead, the push-rod rollers *d*, Fig. 23, are operated by the

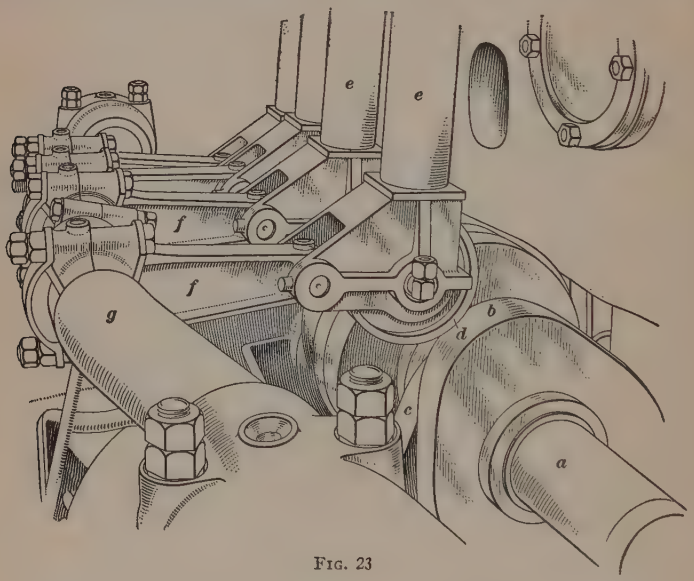

FIG. 23

cams *b*; but when it is desired to have the engine run astern, the reversing cams *c* must be brought into action. To accomplish this, the lay shaft *g* is rotated through 360 degrees, or one full turn. The first half-turn, or 180 degrees of movement, brings it to its outward position, as shown in the illustration, and lifts the cam rollers *d* off the cams *b*. At this stage, the cam-shaft *a* is moved endwise, so as to bring the reversing cams *c* under the raised cam rollers. Continued rotation of the lay shaft through the next 180 degrees, finishing the complete turn, lowers the rollers onto the reversing cams, and the direction of rotation of the engine will be reversed.

The turning of the lay shaft *g* and the shifting of the cam-shaft *a* are accomplished by means of an air cylinder, and are shown in detail in Fig. 24 (*a*) and (*b*). When the engine is to be reversed, the handle *a* is first pulled back toward the operator. This shuts off the fuel oil and causes the engine to stop. An interlocking mechanism prevents the reversing lever *b* from being moved until the handle *a* is in the stop position. In actual operation there are two handles *a* on the quadrant, as illustrated in Fig. 20. Each handle controls the air and fuel oil to the cylinders of one block, or half of the engine.

48. When the fuel has been shut off, the reversing lever *b*, Fig. 24 (*a*), is moved to the left, which turns the link *c* and thus opens the valve *d*, view (*b*). This view is a vertical section of the operating cylinders shown in (*a*). The opening of the valve *d* admits compressed air to the lower end of the cylinder *e* by way of the pipe *f* and so raises the piston in that cylinder. The piston in the cylinder *g* is forced upwards at the same time, as both pistons are fastened to the same piston rod *h*. The upper end of the piston rod is attached to the rack *i* and the bar *j*, and consequently both of these are moved upwards. The cylinder *g* is filled with oil and acts as a dashpot to steady the movement of the lower piston. When the lever *b* is moved to the left, the valve *k* is opened through the motion communicated by the link *l*, and thus the opposite ends of the cylinder *g* are connected. The passage in the valve *k* is small, and the flow of oil through it from the upper end of the cylinder to the lower end is slow, with the result that the movement of the pistons and the rack is gradual. At the same time, the air escapes from the top of the cylinder *e* past the valve *m*, which is opened by the turning of the shaft *c*.

49. The rack *i*, Fig. 24 (*a*), is in mesh with a pinion *n* fixed to the end of the lay shaft *o*, and the rising of the rack thus turns the shaft *o* through a full revolution. At the end of the first half of this revolution, the link *p* has drawn the push rod aside, lifting the cam roller from the cam on the cam-shaft *q*. At that moment, the slanting part of the guide

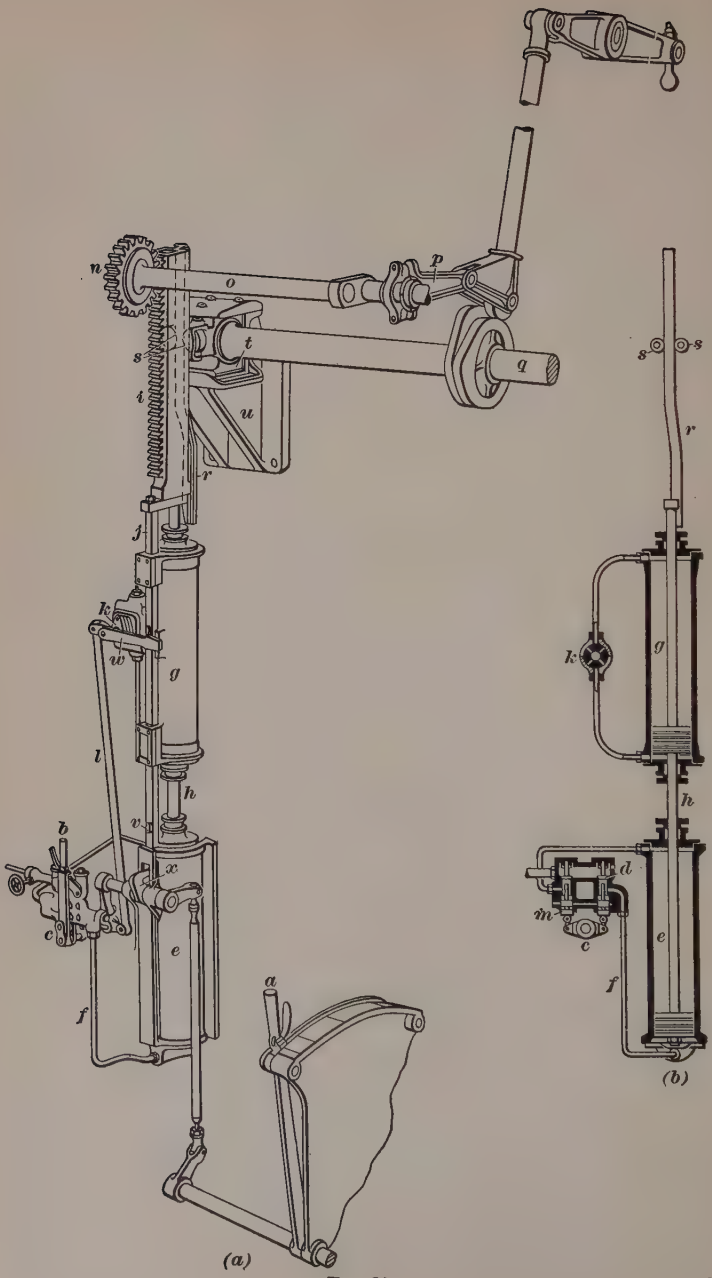

FIG. 24

strip *r* on the back of the rack enters the space between the rollers *s*. These two rollers turn on pins fastened to the bearing *t* at the end of the cam-shaft. The slanting part of the strip *r* thus shifts this bearing *t* to the right, and so moves the whole cam-shaft to the right sufficiently to bring the reversing cam in line with the roller on the push rod. The remaining half-revolution of the lay shaft does not affect the position of the cam-shaft, but it does return the push rod to its original position, with the cam roller resting on the reversing cam. The bearing *t* has grooves that fit collars on the shaft *q*, and slides on the upper face of the bracket *u*. When the projection *v* on the bar *j* rises far enough to strike the arm *w*, the handle *b* is returned to its central position and the oil cock *k* is closed.

50. While the reversing motions are being executed, the operating lever *a*, Fig. 24 (*a*), cannot be moved and remains in the off position. As soon as the air has been released from the air cylinder *e*, however, and the piston rod *h* and the bar *j* have completed their motion, the interlocking arm *x* is free to move forwards, after which the starting lever *a* may be moved forwards on the quadrant. The first forward motion of the lever *a* introduces starting air into the cylinders until a definite point on the quadrant is reached. At this point the rods *n*, Fig. 20, are tripped, which causes the air valves to close. At the same time the fuel pump begins to inject fuel into the cylinders. Up to this point no fuel has been admitted, although the fuel valves start to function as soon as the engine turns over. No fuel is admitted while the lever *a* passes through the starting position, as the suction valves of the fuel pump are held on their seats by an eccentrically fulcrumed rod that is connected through linkages with the lever *a*. When the lever is moved past this position, the fuel-pump suction valves are allowed to open and fuel is delivered by the pump.

51. Fuel Pump.—The fuel pump of the engine in Fig. 20 has individual plungers for each cylinder, all driven by a single eccentric on the engine cam-shaft. The position of the operating handles on the quadrant determines the timing of the clos-

ing of the pump suction valves, and thus the amount of oil pumped per stroke. When, owing to racing of the propeller, the speed of the engine increases too much, a governor acts through a lever directly on the suction valves of the fuel pump and cuts off the oil until the speed is reduced to normal.

The fuel-valve rocker-arms are fulcrumed on eccentrics on the rocker-shaft *j*, Fig. 22. By rotating this shaft slightly by means of a long rod *o*, Fig. 20, from the operating station, the lift of the fuel-valve spindles may be increased or reduced, and the amount of fuel oil admitted to the cylinders regulated to the best advantage, as required for maneuvering purposes.

52. Lubrication and Cooling.—Forced feed is used to lubricate the main bearings of the engine; the oil is then forced through the hollow connecting-rod to the crosshead and the guide. It drains to the oil pan *r*, Fig. 21, and from the pan to an outside settling tank, usually located in the double bottom of the ship, which serves to cool the oil. An independently driven pump returns the oil through a filter to the engine. The working cylinders and compressor cylinders are lubricated by individual lubricators driven from the cam-shaft. The engine is cooled partly by fresh water and partly by salt water. Fresh water is used for the cylinder jackets, cylinder heads, and exhaust-valve cages, whereas the guides, pistons, and thrust bearings are cooled with salt water.

TWO-CYCLE MARINE DIESEL ENGINES

SINGLE-ACTING ENGINES

53. General Features.—A two-cycle Diesel engine that is built for either marine or stationary service is illustrated in Fig. 25. It is a single-acting vertical engine having five cylinders and develops 110 brake horsepower per cylinder at a speed of 225 revolutions per minute. The illustration is a combined front view and section, the section being taken through one working cylinder, the scavenging pump, and the air compressor, in a vertical plane on the center line of the

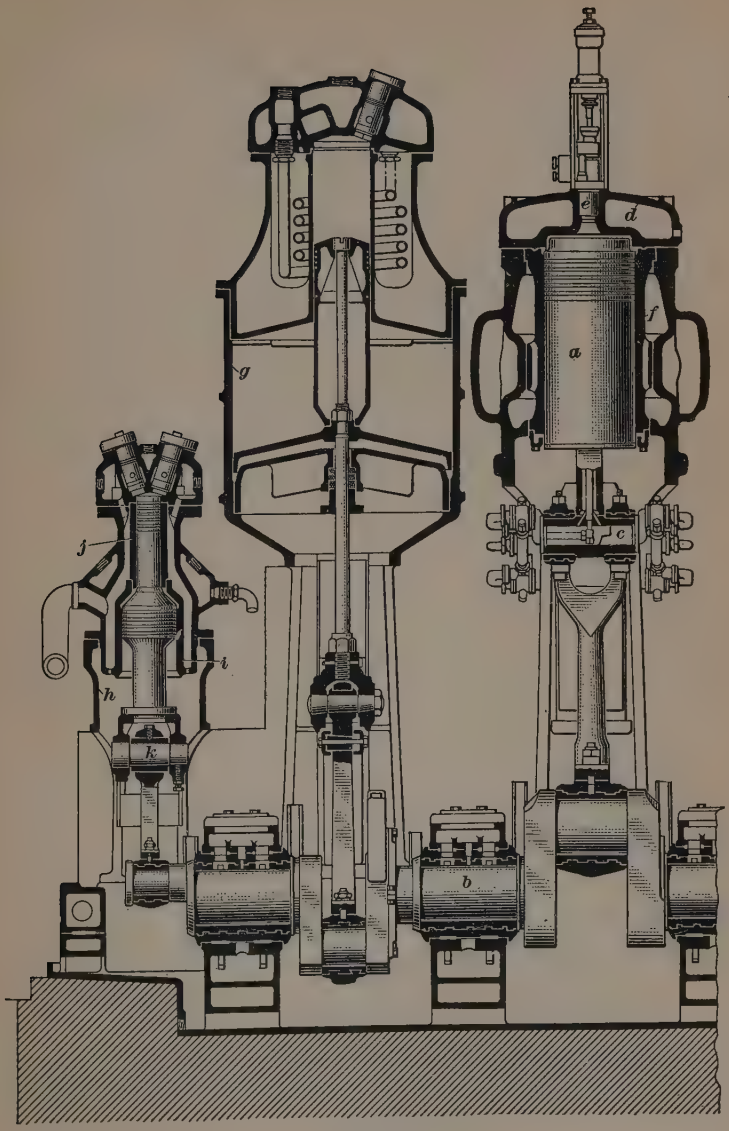

Fig. 25

crank-shaft. The piston *a* of one of the working cylinders, and the crank-shaft *b* are connected through the crosshead *c*. The cylinder head *d* contains only two valves, one being the fuel valve *e* and the other the air starting valve, not shown. Air is admitted to the cylinder and the exhaust escapes from it through ports in the liner *f*, these ports being uncovered by the movement of the piston. The scavenging pump *g* and the air compressor *h* are located forward of the cylinders and are driven from the main crank-shaft *b*.

54. Cycle of Events.—A vertical cross-section of one of the cylinders of the engine in Fig. 25, taken at right angles to the crank-shaft, is given in Fig. 26. The air in the working cylinder is compressed during the upward stroke of the piston to about 500 pounds per square inch, and fuel is injected when the piston reaches dead center. The resulting increase of pressure forces the piston downwards on the expansion, or working, stroke. Toward the end of the expansion stroke the piston uncovers openings, or ports, *a* in the cylinder wall, through which the exhaust gases escape. As the piston continues to move downwards, a moment later it uncovers the ports *b* on the opposite side of the cylinder wall. Scavenging air that has been compressed by the scavenging pump to a pressure of about 4 pounds per square inch enters the cylinder through these ports and sweeps out the remaining exhaust gases. On the next upward stroke the piston first covers the scavenging ports and a short time after it also closes the exhaust ports, causing the entrapped air to be compressed, as at the beginning of the cycle. The piston is built with a ridge on top, so as to assist in guiding the exhaust gases into the exhaust port and to deflect the entering scavenging air in order to prevent it from passing straight across the cylinder into the exhaust ports. The admission of the scavenging air is timed so that the pressure in the cylinder at the beginning of the compression stroke is practically equal to atmospheric pressure at sea level. With engines operating at high altitudes, where the atmosphere is less dense, it will require, therefore, more power to furnish enough scavenging air to

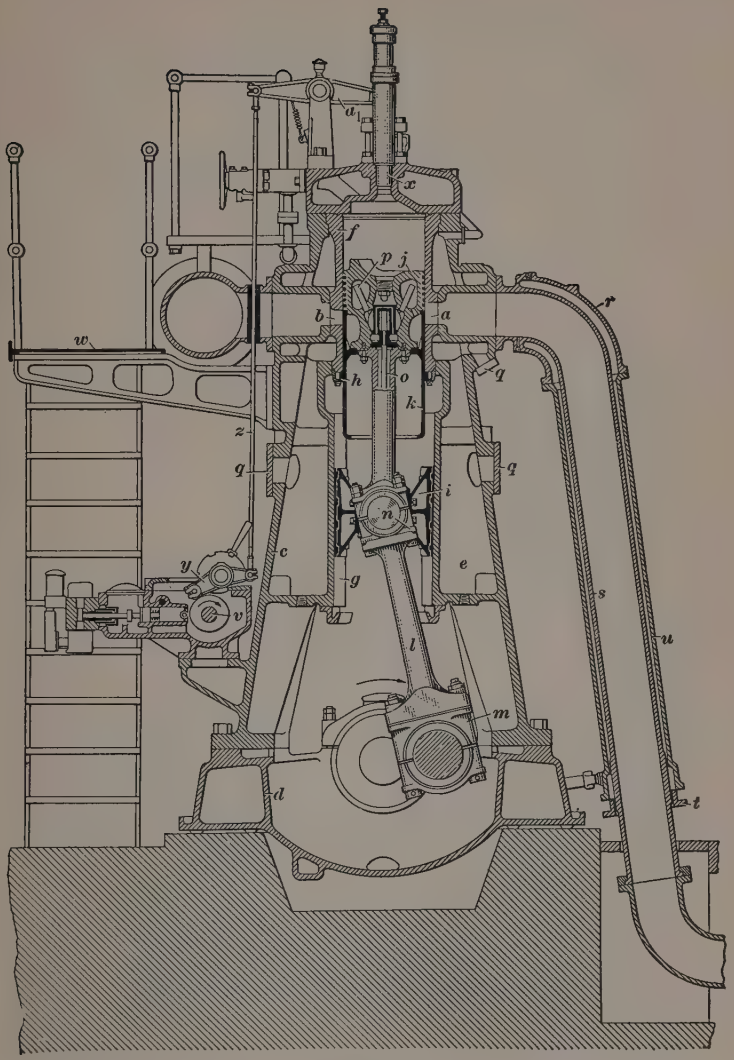

FIG. 26

obtain this condition in the working cylinders, and the engine must be rated slightly lower.

55. Construction.—The frame *c*, Fig. 26, bolted to the top flange of the bedplate *d*, is cast integral with the water-jacket *e* and contains the exhaust passages *a* and the scavenging-air inlet ports *b*. The surfaces of the frame into which the cylinder liner *f* is fitted, and the crosshead guides *g*, are bored in one setting of the frame so as to secure perfect alinement of the cylinder and the guides. The cylinder liner is held at the top in a recess in the top flange of the frame, and is left free to expand at the bottom. A rubber packing ring *h* held to the bottom of the liner prevents leakage from the water-jacket. The liner is easily removable and is made heavy enough to enable it to be rebored when worn. The crosshead *i*, shown in detail in Fig. 27, is a forged block to which the piston rod is secured by two bolts at *a*, and has two projections *b*, to which the forked end of the connecting-rod is attached. The crosshead shoes *c* are cast-steel members faced with babbitt and bolted to the crosshead and are adjustable for wear by shims placed between them and the crosshead. The projections *b* are made hollow to enable cooling water for the piston to pass through the crosshead, and caps are fastened to the projections *b* by the bolts *d*. Thin strips of metal *e* cut with saw-tooth edges are fastened to the shoes to assist in distributing the lubricating oil over the guides.

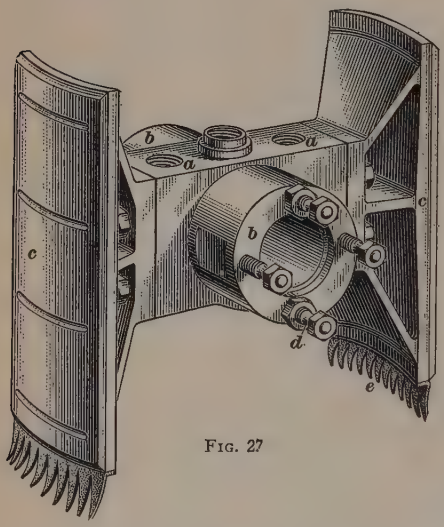

FIG. 27

56. The crosshead guides *g*, Fig. 26, are cast as pads on the frame, instead of being bolted to the frame as is the usual

construction. The piston consists of two parts—the head j, containing the piston rings, and the skirt k. The connecting-rod l is a solid forging to which a cast-steel crankpin box m is bolted at one end. The upper end of the rod attached to the crosshead, is forked and carries two cast-steel boxes n, lined with babbitt, that fit on the two wristpins. Adjustment of both the crankpin boxes and the wristpin boxes is made by means of shims. The five cranks on the main crank-shaft, corresponding to the five cylinders, are set at 72°, so as to give correct balancing. The crank by which the scavenging pump is driven is balanced by counterweights.

57. Water Cooling.—The piston j, Fig. 26, the crosshead i, and the crosshead guides g are water-cooled. The cooling water is led from a common header into the guides of each of the cylinders. From the guides it passes through the hollow crosshead pins and the passage o in the piston rod to the piston j, whence it is conducted to an outlet pipe through the overflow pipe p. Handhole covers q placed at convenient points provide access to the cooling-water space surrounding the cylinder liner for inspection and removal of accumulated scale. The exhaust elbow r and the exhaust pipe s above the engine-room floor are also jacketed and water-cooled, expansion of the inner exhaust pipe being taken care of by the stuffing-box t at the lower end of the exhaust-pipe jacket u.

58. Cam-Shaft.—The cam-shaft v, Fig. 26, driven by spur gears from the crank-shaft, is located at a convenient height so as to be accessible for inspection without compelling the operator to mount the platform w. The fuel-inlet valve x is actuated from the cam-shaft by a cam that acts through a bell-crank y, a tension rod z, and the valve lever a_1. The air starting valve is operated in a similar manner.

59. Scavenging Pump.—The scavenging pump of the engine in Fig. 25 delivers air to the working cylinders at a pressure of about 4 pounds per square inch, besides acting as a low-pressure stage for the air compressor h. A cross-section of the scavenging pump is shown in Fig. 28. The piston has

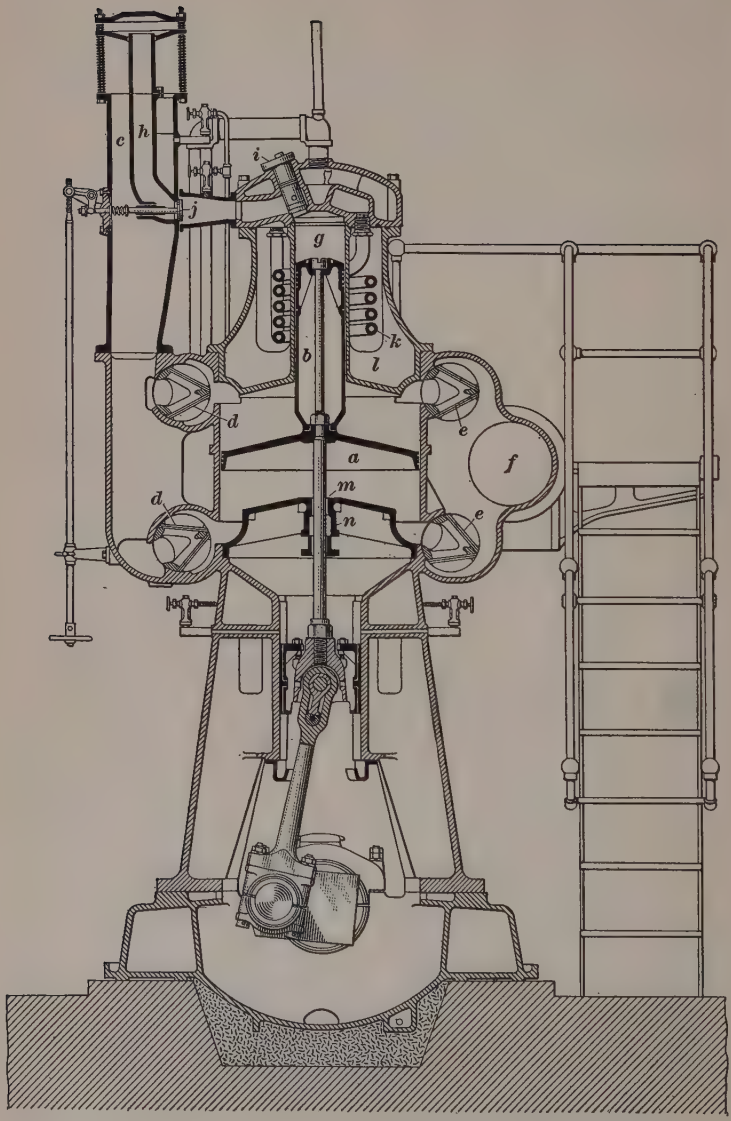

FIG. 28

two steps, the lower and larger step being the scavenging piston *a*, and the upper step the piston *b* for furnishing compressed air to the intermediate stage of the air compressor and for starting the engine. Air is admitted to the pump cylinder through the outer space of the double pipe *c* and the valves *d*, is compressed, and then discharged through the valves *e*, the scavenging pump being double-acting. These valves have two seats provided with slots that are closed by thin steel plates held to the seats by flat steel springs. The air is then collected in the connecting passage *f* and led to the working cylinders.

60. The air supply for the upper cylinder *g*, Fig. 28, is drawn through an inner pipe *h*, that is surrounded by the scavenging-air pipe *c*, enters the cylinder through the valve *i*, and is compressed on the upward stroke of the piston to a pressure of about 200 pounds per square inch. Part of this air is used to furnish the supply for the intermediate cylinder of the air compressor and the remainder for charging the starting-air receiver. When the receiver is fully charged, the valve in the air-receiver line is closed and the compressor receives all of the air supplied by the cylinder *g* of the scavenging pump. The cylinder *g* acts, therefore, as the low-pressure cylinder of the air compressor. A valve *j*, manipulated by hand, enables the operator to vary the amount of air admitted to the cylinder, and therefore the final pressure. Before the compressed air from the cylinder *g* is delivered to the intermediate cylinder of the compressor, it is thoroughly cooled in the coils of an intercooler *k*, located in the cylinder jacket *l*. The piston is guided at the bottom by a bushing *m* in the throat of the stuffingbox *n*.

61. Air Compressor.—The pistons of the intermediate cylinder *i*, Fig. 25, and the high-pressure cylinder *j* are driven directly by the crank-shaft through the crosshead *k*. Other types of the same make of engine, instead of using a two-stage air compressor and scavenging pump, are provided with a three-stage air compressor, the scavenging pump furnishing low-pressure scavenging air only. A sectional view of such a

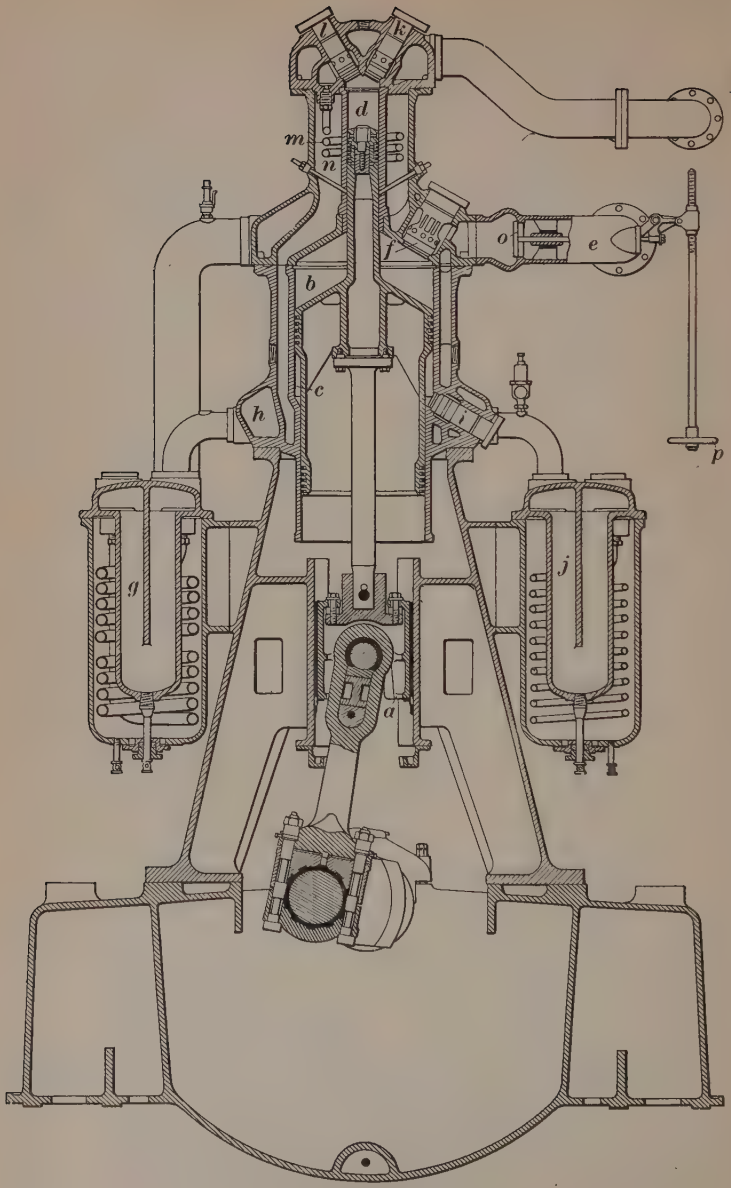

FIG. 29

three-stage compressor is given in Fig. 29. It is driven directly by the engine crank-shaft through the crosshead *a*. The low-pressure cylinder *b* and the intermediate-pressure cylinder *c* are cast integral, but the high-pressure cylinder *d* is bolted to the head of the low-pressure cylinder. The piston is made in three steps of different diameters to suit the cylinder construction, and each section of the piston is fitted with piston rings. In the high-pressure and low-pressure cylinders the air is compressed on the upward stroke of the piston and in the intermediate cylinder on the downward stroke.

62. Air enters the low-pressure cylinder of the compressor in Fig. 29 through the intake pipe *e* and the valve *f* on the suction stroke of the piston, is compressed on the upward stroke to about 50 pounds per square inch, and discharged through a discharge valve, not shown, into the first intercooler *g*, whence it is drawn, on the upward stroke of the piston, into the intermediate cylinder *c* through a valve at *h*. On the downward stroke this air is compressed to about 200 pounds per square inch and discharged through the valve *i* into the second intercooler *j*. From this intercooler the air enters the high-pressure cylinder *d* through a valve *k*, is compressed during the upward stroke of the piston to about 1,000 pounds per square inch, and discharged through a valve *l* into the aftercooler coils *m* located in the water-jacket *n* of the high-pressure cylinder. From the aftercooler the air passes through an oil separator to the air receiver. The final pressure of the air may be varied by regulating the amount of air drawn into the low-pressure cylinder by means of the valve *o*, operated by the hand wheel *p*.

63. Fuel Pump and Governor.—Two views of the fuel pump used on the engine in Fig. 25 are shown in Figs. 30 and 31. One pump is provided for each power cylinder and a set of two pumps is combined in one unit driven from the camshaft by a single eccentric *a*, Fig. 31. The fuel pump plunger *b* is operated at a constant stroke by the eccentric strap *c* and is guided by the crosshead *d*. The intake valve *e* of the pump is operated by an eccentric strap *f* through the bell-

crank *g*. The bell-crank is fulcrumed on the eccentric pin *h* and its short arm carries a block that fits in the jaws of the yoke *i*, fastened to the valve rod *j*. On the upward stroke of the plunger *b*, oil is admitted from the oil chamber *k* through

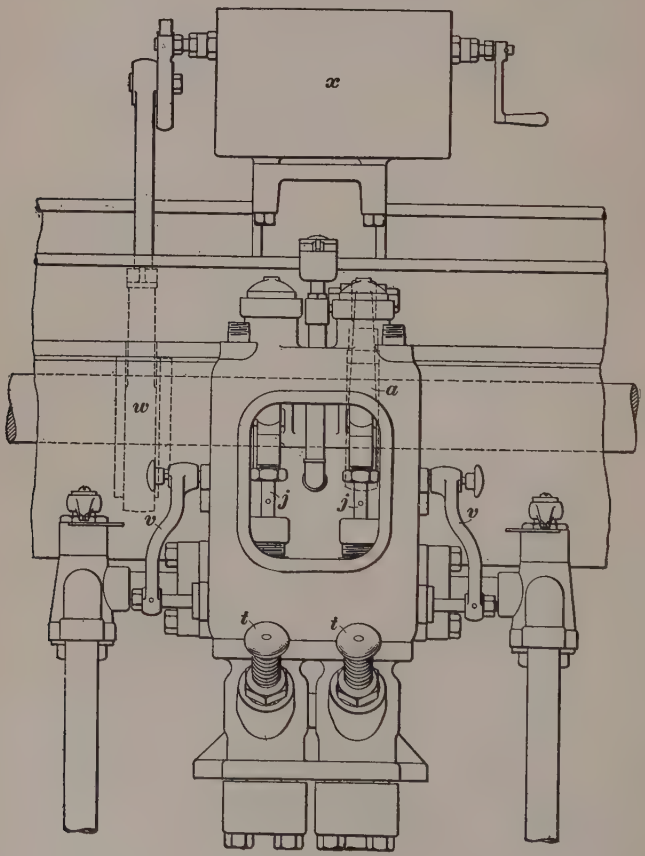

Fig. 30

the intake valve *e* into the space *l* and on the downward stroke the oil is discharged through the discharge valve *m* and the pipe *n* into the fuel nozzle in the cylinder head. The amount of oil injected is regulated according to the engine speed by a centrifugal governor *o*, driven from the cam-shaft.

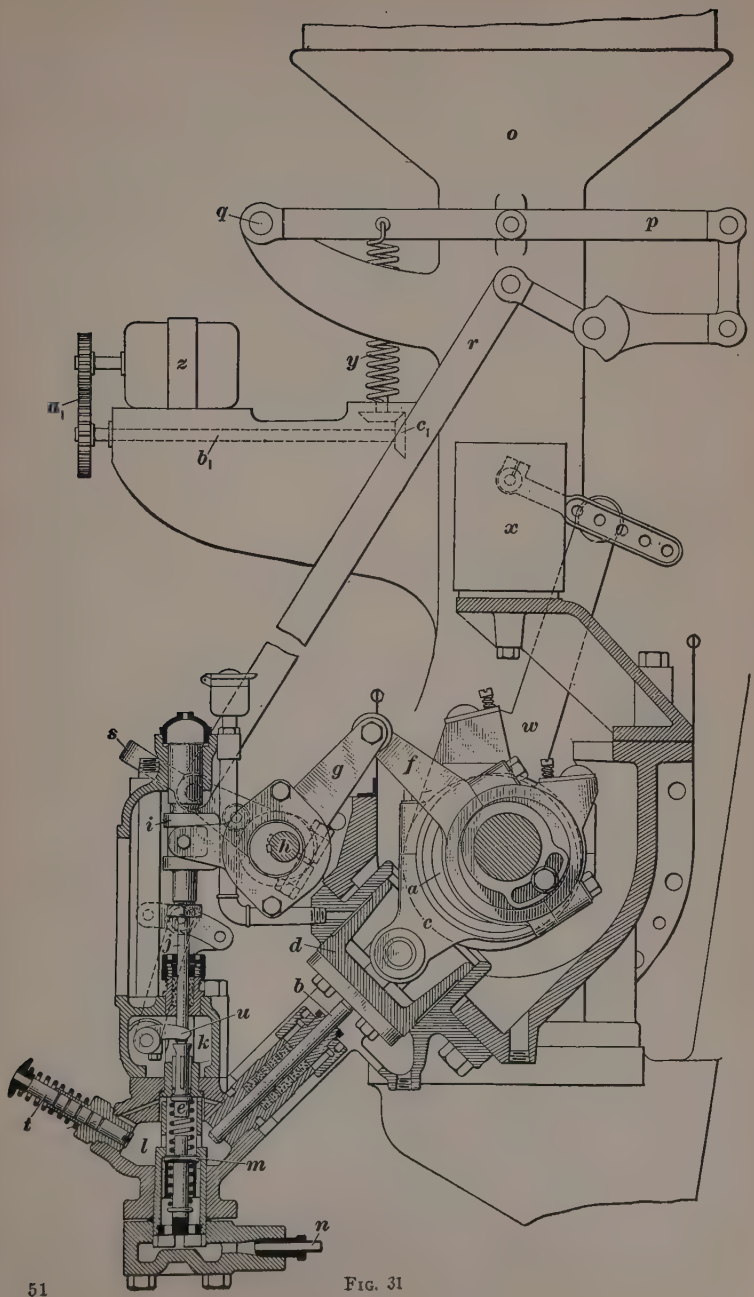

FIG. 31

64. When the speed of the engine rises above normal, the weights in the governor *o*, Fig. 31, are forced apart, raising the lever *p*, which is pivoted at *q*. This results in a downward motion of the rod *r*. The rod *r* is connected with a lever *s* keyed to the movable eccentric fulcrum *h*, so that, when the rod *r* is moved downwards, the fulcrum *h* moves in the opposite direction and causes the suction valve to open. As the fulcrum *h* is lowered or raised according to the speed of the engine, the suction valve opens earlier or later, respectively, in relation to the discharge stroke of the plunger. When the suction valve opens during a portion of the discharge stroke, which happens at excessive speeds, part of the fuel oil is returned to the suction side of the pump, and thus the speed of the engine is reduced.

65. Each pump is equipped with a hand-operated plunger *t*, Figs. 30 and 31, to prime the pipe lines and nozzles. A small finger *u*, operated by a lever *v* on the outside of the pump, Fig. 30, may be used to depress the suction valve so as to make any one pump inactive. Both the suction valve *e* and the discharge valve *m*, Fig. 31, have extensions directed toward each other, which enables the suction valve to be depressed to a point where it will actually lift the discharge valve off its seat and allow the oil to flow through the pump. This is done when the pump becomes air bound, that is, when the pump refuses to operate owing to an accumulation of air in the pump body. A separate eccentric *w* serves to operate the force-feed oil pump *x*. The governor *o* is equipped with an auxiliary spring *y*, outside the governor housing. By varying the tension of this spring, a variation may be made in the motion of the governor lever *p*, and this will ultimately result in a change in engine speed. The tension of the spring may be varied by hand or through a reversible electric motor *z*, controlled from the switchboard, and operating through the gears a_1, the spindle b_1, and the bevel gears c_1.

66. Fuel Valve.—A sectional view of the fuel atomizing valve is shown in Fig. 32. The body of the valve fits into an opening in the cylinder head. Inside the body is a long tube *a*

that carries at its lower end a series of perforated washers *b*, the holes in which are staggered. Within the tube is the needle valve *c* that can be lifted from its seat *d* by the valve lever *e*, operated by a rocker-arm and a tension rod from the cam-shaft. The needle is held to its seat by the pressure of a coil spring *f*. The fuel enters the passage *g* and flows down the space *h* between the valve body and the tube *a* to an annular chamber *i* above the perforated washers *b*. Air from the high-pressure stage of the compressor is admitted to the fuel valve at *j* and follows the passage *k* between the needle valve and the tube *a*, emerging through drilled passages at *l*. When the needle valve is lifted the air forces the oil through the perforations of the washers *b* and the sprayer nozzle *m* into the combustion chamber. If it becomes necessary to do so, the fuel-valve needle can be removed from its casing after dismantling the valve lever *e* and the spring casing *n*, without disturbing the fuel-valve casing itself. This is very convenient when it is desired to inspect the needle.

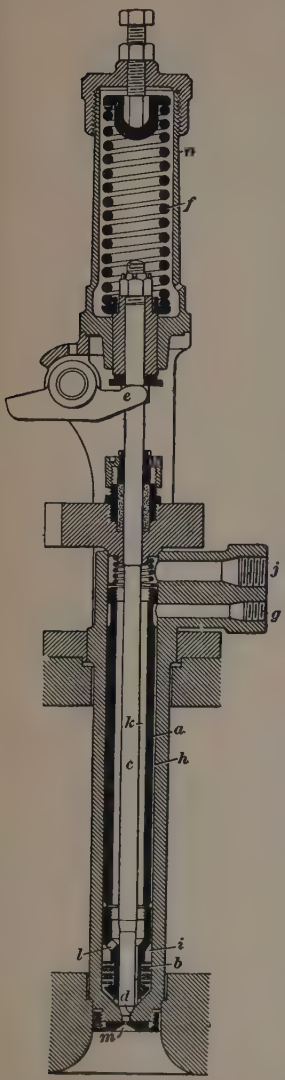

FIG. 32

67. Lubrication.—The bedplate *d*, Fig. 26, is of the closed-pit type and gathers the lubricating oil from the entire engine. This oil then flows by gravity into a filter, from which it is raised by a small pump, driven by the engine itself, to an overhead tank from which the engine is supplied. The bearings supporting the cam-shaft are ring-

oiled and the eccentrics on the cam-shaft, which operate the fuel pump, are supplied with oil from oil cups. The main bearings are provided with oil rings that dip into an oil well below. They also receive a stream of oil from the gravity oil system, insuring a fresh supply of cool oil in the oil well at all times. Each crosshead-pin bearing is supplied with oil from an individual lubricating pump, driven by means of a link from the cam-shaft.

68. Step-Piston Marine Diesel Engine.—The engine shown in perspective in Fig. 33 is a four-cylinder marine Diesel engine working on the two-cycle principle, and Fig. 34 is a cross-section of the engine through one of the cylinders. In Fig. 33 the light steel covers of the crank-case are removed, showing the cranks, connecting-rods, and the lower ends of two of the pistons. The connecting-rod *a*, at the after end of the crank-shaft, drives an air compressor *b* that furnishes air at high pressure for the injection of the fuel into the cylinders. The same compressor also furnishes air to the reservoirs in which air for starting the engine is stored under pressure. The columns *c* that support the cylinders are removable, thus enabling the entire crank-shaft to be taken out of the crank-case.

69. As shown in the sectional view, Fig. 34, the piston is in two parts of different diameters. The smaller end *d*, working in the top of the cylinder, is the main piston, or working piston, and the larger section *e* is the scavenging and starting piston. The combustion of the fuel charge takes place in the chamber *f*, into which the oil is sprayed from the atomizer *g* by air at high pressure. The fuel pump—one for each cylinder of the engine—forces a quantity of oil down into the passage surrounding the tip of the atomizer *g*. At or near the end of the upward stroke of the piston *d* the spindle *g* is lifted from its seat by the action of the cam *h* on the cam-shaft *i*. The cam lifts the rocker *j*, pivoted at *k*, and so forces up the rod *l*, which is connected to the lever *m* that raises the spindle *g* against the action of the coiled spring at the top. As soon as the spindle is raised, the air pressure above the oil drives

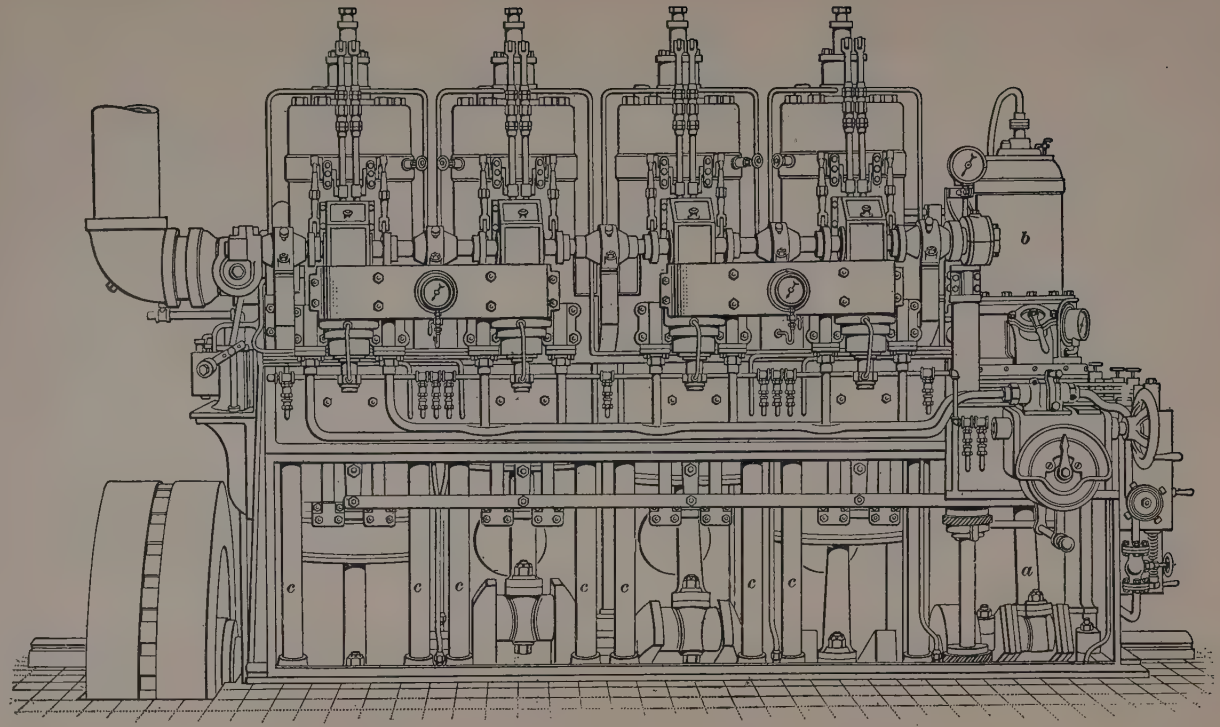

Fig 33

the oil through the spray orifice into the chamber *f*. Here it meets the highly compressed air, which is at a temperature high enough to ignite the atomized oil, and combustion follows. The piston is then driven down on its working stroke by the expansion of the gases formed by the combustion.

70. When the piston *d*, Fig. 34, has almost reached the bottom of its stroke, it uncovers the exhaust ports *n* in the side of the cylinder and the burned gases escape into the water-jacketed exhaust pipe *o*. A brief instant later the piston in its descent uncovers the port *p*, which leads to the chamber *q* in which is stored clean air that has been compressed by the scavenging piston *e*. Uncovering of the port *p* allows this air to rush into the cylinder, thus driving out the remainder of the burned gases and leaving the working cylinder filled with clean air. On the same downward stroke, a partial vacuum is formed in the annular space *s* by the descent of the scavenging piston, and air rushes into that space past the valve *r* and through a curved port leading into the top of the scavenging cylinder, as shown by the dotted lines. As the pistons move upwards, the air in the working cylinder is compressed into the space *f* and the air in the space *s* is compressed and forced up past the valve *t* into the chamber *q*, ready to scavenge the cylinder at the end of the next downward stroke. The chamber below the valve *r* is in direct communication with the outside air.

71. Starting of the engine shown in Fig. 33 is accomplished by admitting air from the starting-air reservoirs to the space *s*, Fig. 34, above the scavenging pistons. This air is led by a pipe to the inlet *u*, below the small piston *v*, which is connected by a short rod to the sleeve valve *w*. A pipe *x* connects the space below the piston *v* with the annular space *y* in the case surrounding the sleeve *w*. As soon as starting air is admitted through the connection at *u*, the pressure forces the small piston *v* upwards and so moves the sleeve *w* upwards, until it is held firmly against the valve seat *z*. This movement brings the annular groove *a'* in the sleeve *w* up until its lower edge is in line with the lower edge of the annular space *y*. The

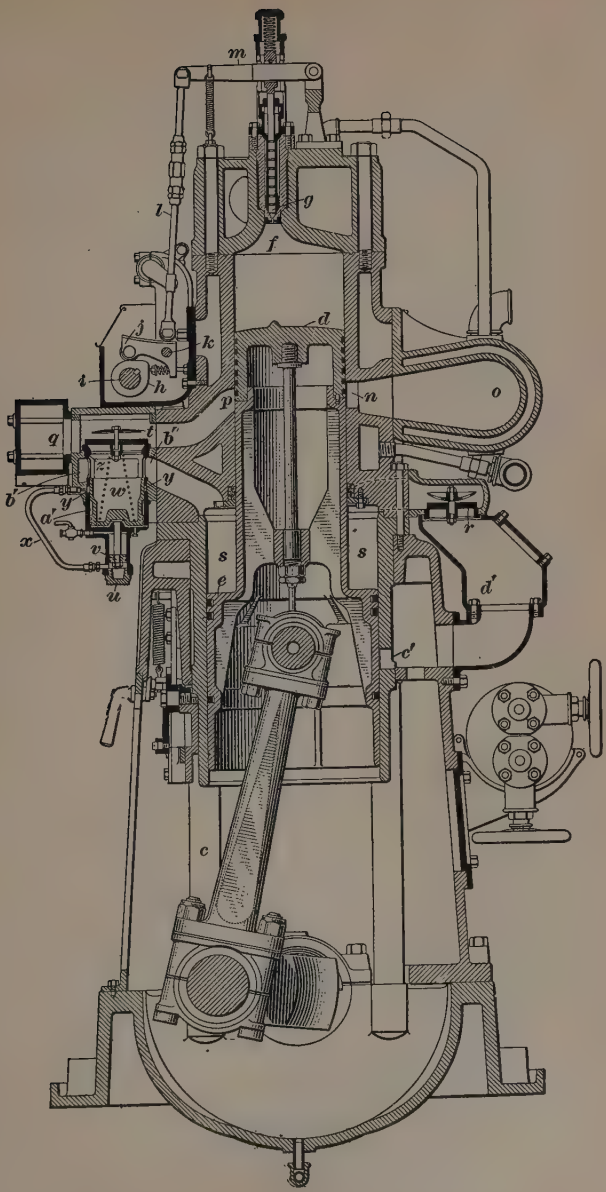

FIG. 34

upper part of the groove a' then communicates with the space b', which opens into the port leading to the space s. At the same time, air flows through the pipe x into the annular chamber y and thence by way of the groove in the sleeve w to the space b', from which it passes into the scavenging cylinder and starts the engine. This air, which is at about 175 pounds pressure, is prevented from passing into the working cylinder by the closing of the sleeve w against the seat z. When the scavenging piston e reaches the lower end of its stroke it uncovers the port c' and the starting air is exhausted into the chamber d', from which it escapes to the outer atmosphere. The starting air need not have the high pressure commonly employed for starting Diesel engines, because the starting piston has a large area. As the starting piston is not subjected to the high compression and combustion temperatures of the working piston, there will be no danger of fractured pistons due to the contact of comparatively cold starting air with hot pistons.

72. Governing of the engine shown in Fig. 33 is brought about by varying the quantity of oil delivered to the cylinder by the fuel pump. There is a fuel pump for each cylinder, and all of them are under the control of a centrifugal governor. The governor is so arranged that as the speed increases the length of discharge stroke of each pump is shortened, thus decreasing the quantity of fuel sent to the cylinder. By means of a suitable attachment, the speed of the engine may be altered while the engine is running. Similarly, it is possible to adjust the governor for a certain maximum speed, and when the engine reaches this speed there will be no further increase. This feature is of value to prevent racing of the engine in a heavy sea.

73. Airless-Injection Engine.—A two-cycle marine Diesel engine built in capacities up to 60 horsepower is shown in cross-section in Fig. 35. The engine belongs to the airless-injection class of engines; that is, the fuel charge is atomized and injected by means other than the action of compressed air. This is accomplished by the introduction of a preignition

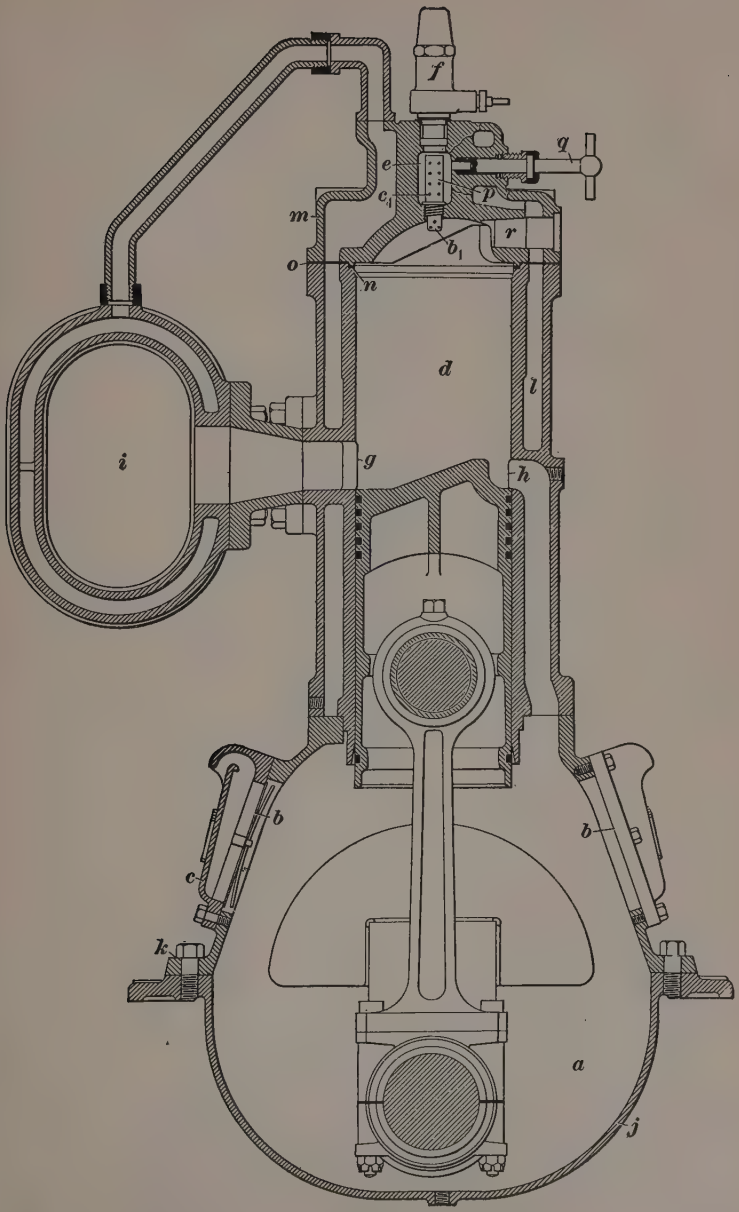

Fig. 35

chamber in the cylinder head and of a specially constructed spray nozzle. During the upward stroke of the piston, a suction is created in the crank-case *a*, causing pure air to be drawn into the crank-case through the air valves *b* located in both handhole covers *c*. At the same time the air already contained in the cylinder *d* and in the preignition chamber *e* is compressed to about 450 pounds per square inch. At the end of the compression stroke, the fuel is injected into the hot compressed air through the spray nozzle *f* and combustion occurs, driving the piston downwards and compressing the air in the crank-case. As the piston approaches the end of the downward stroke, the exhaust port *g* is uncovered, and immediately thereafter the air-inlet port *h*, allowing the exhaust gases to escape through the port *g* into the water-cooled exhaust manifold *i* while compressed air from the crank-case *a* enters the cylinder through the port *h*, clears the cylinder and fills it with clean air for the next compression stroke. The piston is then ready for its next upward stroke and the cycle is completed.

74. The engine shown in Fig. 35 is of the trunk-piston type. The bedplate *j* supports the crank-case *k*, to which is bolted the cylinder *d*, cast integral with the water-jacket *l*. The cylinder head *m* is bolted to the top of the cylinder. Between the cylinder and the cylinder head two gaskets are used. At *n* is a soft-copper gasket that seals the high-pressure air within the cylinder and at *o* is a leather gasket that seals the circulating water. The cylinder head contains the spray nozzle *f*, the preignition chamber *e*, the combustion tube *p*, the plug *q* for relieving the compression, and the chamber *r* for the starting mechanism. The spray nozzle, shown in detail in Fig. 36, is installed in the cylinder head directly over the tube *p* in the chamber *e*, Fig. 35. The fuel enters the nozzle from the fuel pump through the pipe *s*, Fig. 36, completely filling the passages *t*, *u*, and *v*, all air having first been expelled from these passages by opening the needle valve *w* and operating the fuel pump by hand. Toward the end of the stroke of the fuel-pump plunger, the pressure of the oil in the nozzle

passages and in the space u becomes sufficient to raise the needle valve x against the action of the spring y, and the oil is forced from the passage t through the fluted passage v, in which it is thoroughly atomized. The flutes are so shaped that they give to the oil a whirling motion as it leaves the nozzle through the needle hole z. The needle valve x is lifted

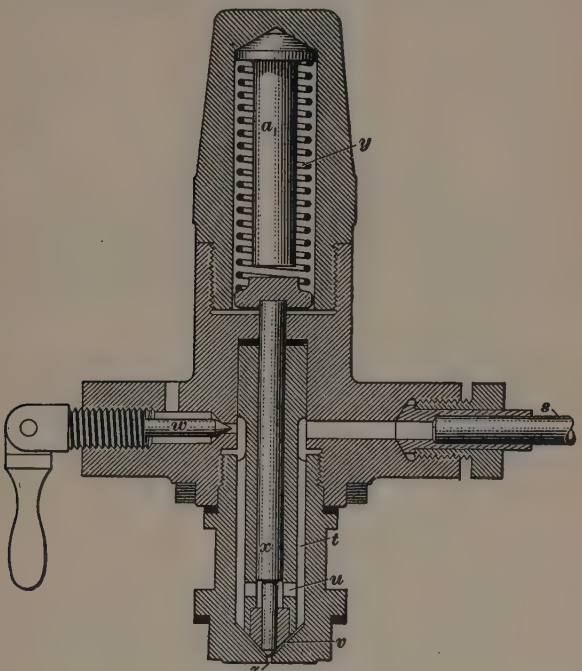

FIG. 36

from its seat when the pressure in the oil line is about 900 pounds per square inch. The spindle a_1 serves as a stop to prevent the needle from rising farther than is necessary.

75. The oil spray, after leaving the nozzle, enters a perforated tube p, Fig. 35, placed in the preignition chamber e. The compression in the cylinder forces the air from the cylinder through the holes b_1, drilled in the closed end of the tube p, into the tube and into the surrounding chamber e. Inside the tube the air meets the oil being sprayed by the

spray nozzle into the open end of the tube. The mixture in the tube is too rich to be exploded, but a portion of the oil is vaporized and passes from the tube through the holes c_1 into the surrounding chamber e, where it mixes with a larger quantity of highly compressed air. Rapid combustion and greatly increased pressure then occur in the preignition chamber, forcing the gases back into the perforated tube at a temperature of about 2,000° F., causing all the oil inside the tube to be gasified and discharging the vapors during the early part of the down-

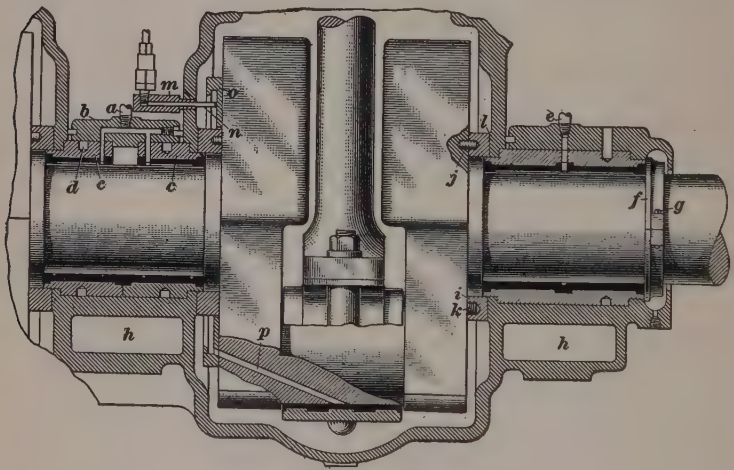

Fig. 37

ward stroke of the piston into the cylinder, in which they are burned completely. Spraying continues until the pressure in the oil line is relieved by the fuel pump, and the fuel needle then snaps back on its seat. During the remainder of the downward stroke of the piston the tube p is scavenged by the expansion of the air in the chamber e.

76. The main bearings of the engine in Fig. 35 are shown in Fig. 37. They consist of heavy cylindrical cast-iron shells lined with babbitt. By removing the oil tube a and the bearing cap b from each of the inside main bearings of the engine, two pieces c forming the upper half may be lifted out. This is done by inserting pins in the holes d provided for

the purpose, and pulling each piece sidewise so as to clear the crank-cases. The lower half of each bearing is also in two pieces. To remove these, one of the pieces is pushed around the shaft by means of a piece of hardwood while the other piece is held stationary. When the piece has been turned clear around, it can be lifted out.

The end main bearings are so constructed that the top and bottom halves each form one piece. To remove the top half, the oil tube *e* and the bearing cap are first removed, and then the oil ring *f*, which may be done by taking out the screws *g*. The top is then slipped sidewise and lifted out. The bottom half is turned around the shaft and lifted out in the same way as the bottom half of the inside bearings. The lower half of each main bearing is water-jacketed and a circulating pump supplies water to the jackets *h*. An overflow pipe is led from one of the main bearings to the circulating-water overflow line or directly overboard. To prevent leakage of compressed air from the crank-case past the bearings, sealing rings *i* are provided at the ends of each bearing. These rings are mounted on a shoulder on the crank-shaft and turn with it, being driven by the pins *j*. The springs *k* keep the ring in contact with the inner face *l* of the crank-case, which is lapped so as to form a tight joint.

77. The air suction valves *b*, Fig. 35, provided at either side of the crank-case, are shown in detail in Fig. 38. The cover-plate *a* has a number of slots *b* covered by strips *c* made of flat spring steel that serve as valves. These strips are held in place by a clamp bar *d* and are prevented from opening too far by the stops *e*, which are set about $\frac{1}{2}$ inch away from the strips at the outer end.

78. Fuel Pump and Governor.—The engine is made in units of two cylinders or a multiple of two cylinders. In Fig. 39, which shows the arrangement of governor and fuel pump for a two-cylinder unit, the eccentric *a*, keyed to the crank-shaft *b*, operates the fuel pump plunger *c* of one of the cylinders by means of the eccentric strap *d*, and the eccentric *e* the fuel pump plunger of the second cylinder by

means of the eccentric strap *f*. The latter pump plunger is not shown in the illustration. The pump suction valves *g*, only one of which is shown, are operated by the eccentric *h* on the crank-shaft and the trip rod *i*. The governor *j*, mounted on the crank-shaft, controls the action of the suction valves by varying the position of the eccentric *h*.

79. On the suction stroke of the pump, the plunger *c*, Fig. 39, is forced downwards by the action of a spring *k*, drawing oil into the chamber *l* through the suction valve *g* from the space *m*, into which the oil runs by gravity from the

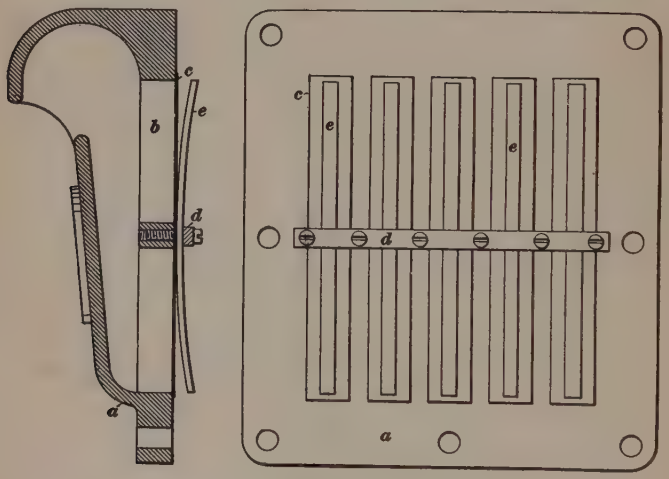

FIG. 38

main fuel tank. The pump plunger *c* finally comes to rest on its collar *n*. The eccentric strap *d* is attached to a crosshead *o* into which an adjusting screw *p* is screwed. On the upward stroke of the crosshead *o*, the adjusting screw *p* strikes the plunger *c*, driving it upwards. As the suction valve *g* is closed by the action of the eccentric *h* and the trip rod *i*, the oil in the chamber *l* is forced through the discharge valve *q* and the pipe *r* to the spray nozzle, from which it enters the combustion tube in the preignition chamber through a number of small grooves. As the pump plunger continues to travel upwards, the spraying of the fuel oil into the com-

bustion tube continues until, through the action of the trip rod *i* and the eccentric *h*, the suction valve *g* is lifted from its seat. This relieves the pressure in the chamber *l* and the discharge valve *q* is automatically closed by the pressure in the pipe *r*, thus preventing the oil in the pipe from draining back into the chamber *l*. As the suction valve is now open, the oil displaced during the remainder of the upward stroke of the fuel pump plunger is returned through the suction valve to the chamber *m* and the fuel line.

80. The governor *j*, Figs. 39 and 40, is of the centrifugal type, each of the two weights *s* being hinged on a pin at one end. As the engine speeds up, these weights swing outwards, their outward movement being opposed by the springs *t*, the tension of which can be changed by means of the two screws *u* on the rim of the governor housing. To each of the governor weights is attached a link *v*, the other end of which is fastened to the eccentric *h* that operates the trip rod *i*. The spreading of the weights causes the link to advance the eccentric, thus causing the trip rod to lift the suction valve earlier, relieving the pressure in the fuel pump and thereby cutting off the fuel supply to the cylinders. When the engine is brought to a stop, the shock of the weights striking the governor housing is cushioned by the springs *w*. The speed of the engine can be increased by tightening the springs *t* by means of the screws *u* and decreased by loosening them, care being taken to give both screws the same number of turns.

81. The point at which the fuel injection starts in relation to the crank travel may be varied by inserting or removing thin washers under the head of the adjusting screw *p*, Fig. 39. The duration of the spray, which is normally under control of the governor, may be varied by hand by means of a handle *x* fastened to the rod *y*. On the other end of this rod is a gear *z* that meshes with the gear a_1 on the trip rod *i*. Turning the handle one way or the other will therefore turn the trip rod, and as its end is threaded into the crosshead b_1, the rod will be either lengthened or shortened, thus causing it to raise the suction valve earlier or later.

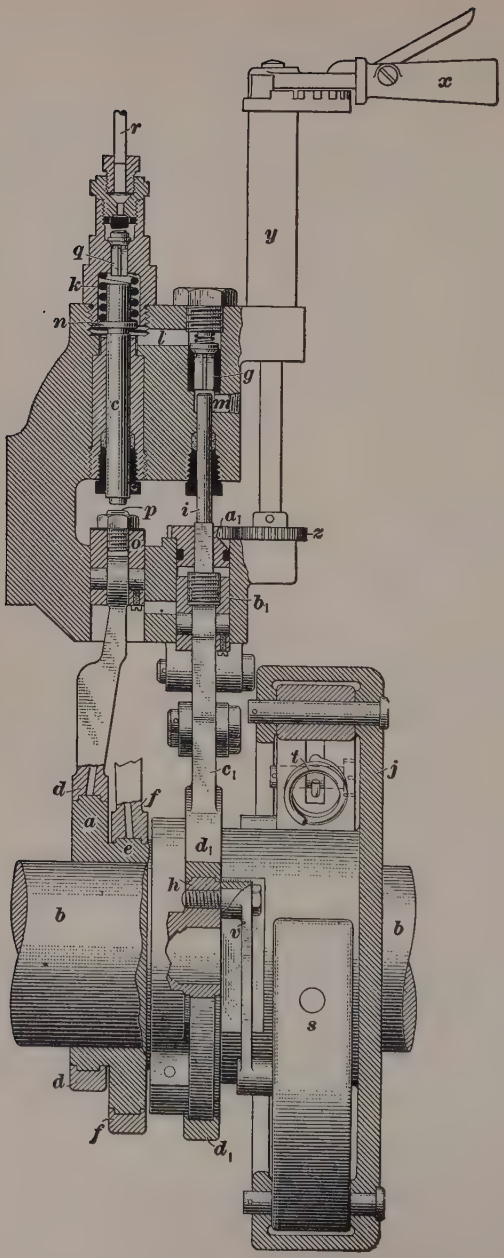

FIG. 39

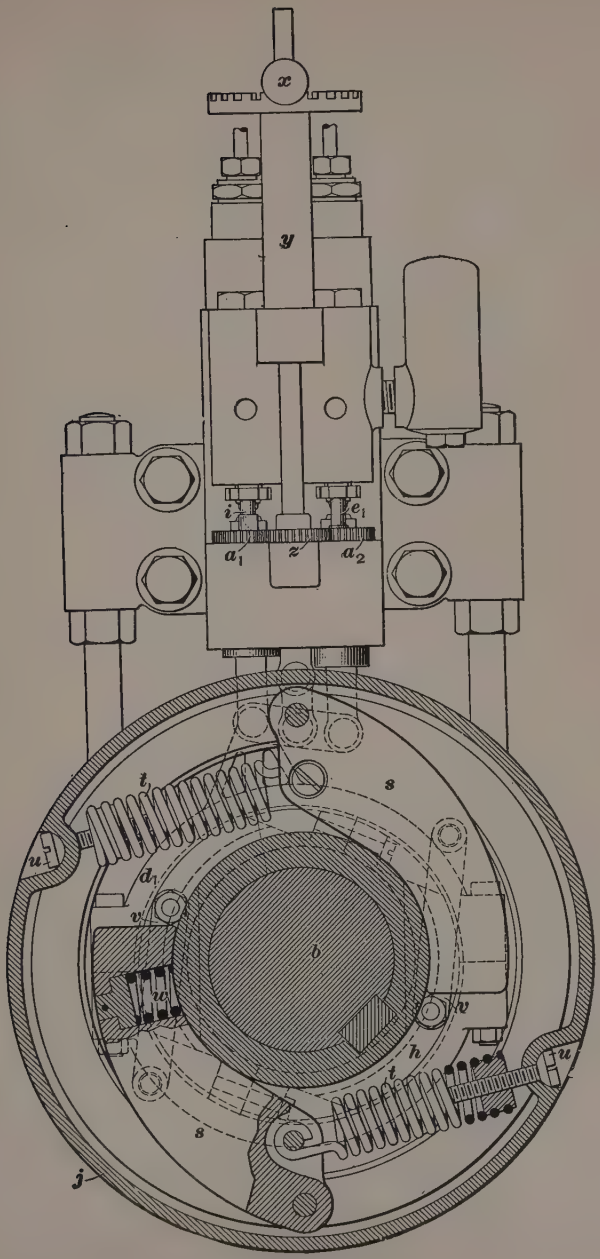

FIG. 40

The operation of the two suction valves is shown in detail in Fig. 41. The trip rod i for the first suction valve is operated directly by the arm c_1 fastened to the eccentric strap d_1 on the eccentric h, the position of which is varied by the governor, and the trip rod e_1 that opens the second suction valve 180° later than the first one, indirectly by the eccentric h and the strap d_1 through the lever f_1 and the link g_1. The lever f_1 is fulcrumed on the pin h_1 on the link i_1. This arrangement is necessary because the arm c_1 is an extension of the eccentric strap d_1, and the pin j_1 moves back and forth in a horizontal direction as the eccentric rotates. The lever f_1 must move with it, and this is made possible by mounting the pin h_1 on the movable link i_1. The gear a_2 meshes with the gear z.

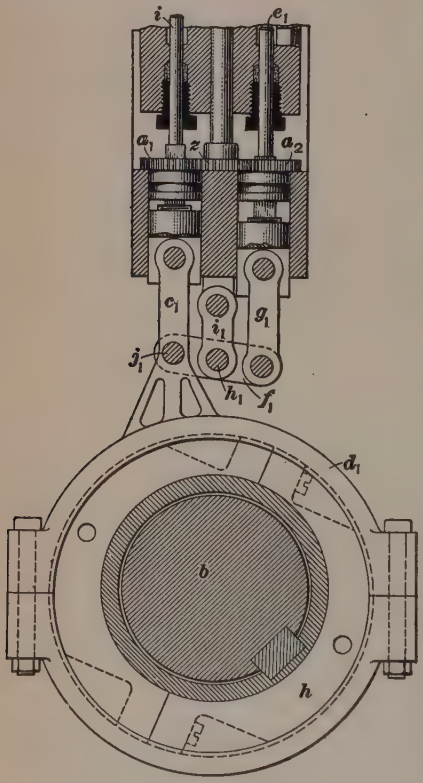

FIG. 41

82. Starting the engine shown in Fig. 35 is accomplished by admitting air from a storage tank to one of the engine cylinders through an air starting device in the chamber r, details of which are shown in Fig. 42. The starter housing, as shown in (a), is tapered at a to fit the inner wall of the cylinder head and prevent leakage of compression from the cylinder into the water-jacket. Leakage of cooling water that surrounds part of the starter housing is prevented by the rubber gasket b. The housing is firmly fastened to the cylinder head by two

bolts at *c*. It contains the valve *d*, controlled by a handle *e*, and the valve *f*, view (*b*), mechanically operated by a cam on the engine crank-shaft. When the engine is to be started, the handle *g* is raised, causing the rod *h* to bring the cam roller in contact with the starting cam on the cam-shaft. This forces the link *i* to rock on the pin *j* at each lift of the starting cam.

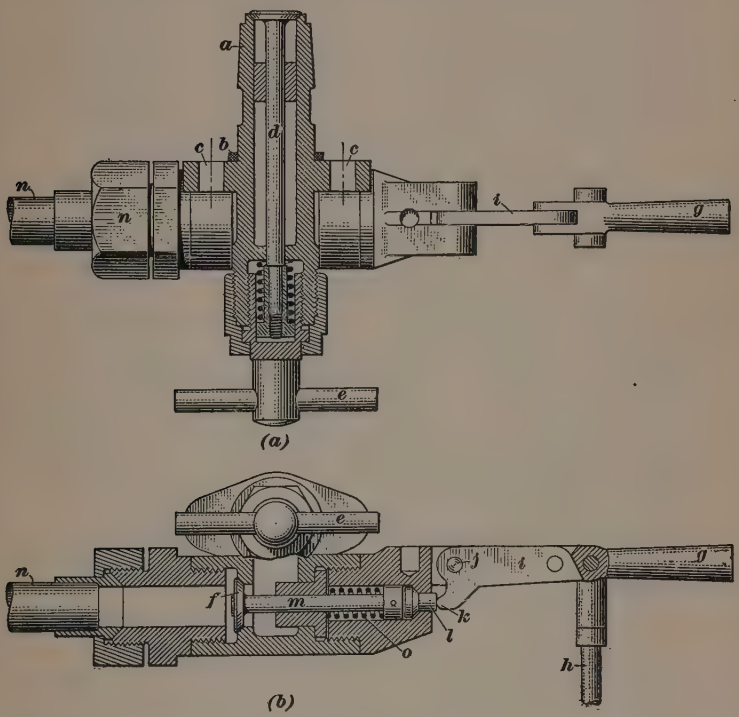

FIG. 42

The short arm *k* then forces the plunger *l* against the valve stem *m*, opens the valve *f*, and allows compressed air from a storage tank to flow through the pipe *n* into the cylinder at the proper time. After the engine has turned over a sufficient number of times to pick up operation on fuel, the handle *g* is released.

83. To restore the pressure in the air-storage tank after the engine has been started, the fuel supply to one of the engine

cylinders is cut off and the cylinder is used as an air compressor. The handle *e*, Fig. 42, is screwed in so as to open the valve *d* and thus admit the compressed air from the cylinder to the air line leading to the storage tank. When the required pressure has been reached in the storage tank, the valve *d* is closed and fuel is again admitted to the cylinder. While the cylinder is pumping air, the valve *f*, view (*b*), is held on its seat by a strong spring *o*, and acts as a check-valve. The plunger *l* has a conical seat and thus acts as a safeguard against any air leakage. It is good practice, in installations using one of the engine cylinders as a compressor, to charge at least one reserve tank besides the regular air receiver. If the engine fails to start, or if the air supply in the receiver becomes exhausted in some other way, the operator still has the reserve tank to draw on.

84. Before the engine is started, the plug *q*, Fig. 35, is removed from the cylinder head, heated to a bright red, and again inserted. It then acts as an aid in the primary combustion of the gasified fuel in the preignition chamber *e* during starting. After the engine has been started, the temperatures developed in the preignition chamber are sufficient to keep the starter plug hot. The plug may be removed when it is desired to relieve the compression in the cylinder.

The pistons, wristpins, main bearings, crankpins, water-circulating pump, and fuel pump are all lubricated by a force-feed lubricator. In Fig. 37 are shown the tubes *a* and *e* that carry the oil to the main bearings. Lubricating oil for the crankpins is led through the plug *m* and the tube *n* to a groove in the oil ring *o*, mounted on the side of the crank, and reaches the crankpin bearing through the passage *p* drilled through the crank and the crankpin.

85. Two-Cycle Semi-Diesel Engine.—A three-cylinder two-cycle engine is shown in perspective in Fig. 43 and sectional views of the same engine are shown in Fig. 44 (*a*) and (*b*), corresponding parts in both illustrations having the same reference letters. The cylinders are cast separate and are bolted to the base of the engine, and the cranks are set at

equal angles of 120 degrees. Air is drawn into the crank-case through the elbow *a* and the ports *b* and is compressed on the downward stroke of the piston. It then flows through the transfer port *c* and into the cylinder through the port *d*, where it strikes the deflector *e* and is thrown upwards into the upper end of the cylinder. The exhaust gases escape through the port *f* into the exhaust manifold.

86. The air compressed in the crank-case and admitted to the cylinder in Fig. 44 is unmixed with fuel. The fuel is

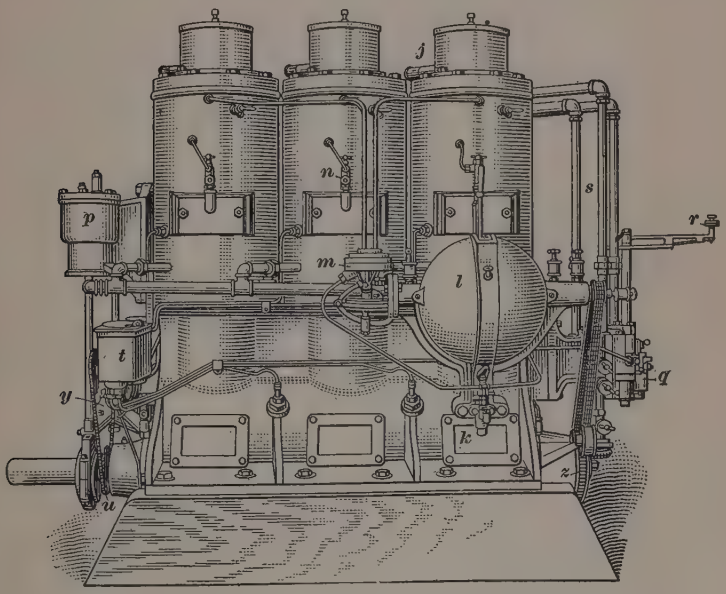

FIG. 43

injected in a fine spray through a needle valve *g* at the top of the cylinder. This injection of fuel takes place just before the piston reaches the upper end of its stroke, when the air has a high temperature due to its being compressed by the piston on its upward stroke. The needle valve is so located that it sprays the fuel directly against the lip *h* of the hot ball *i*. This hot ball is a casting bolted to the cylinder head and is the means used to ignite the fuel charge. When the

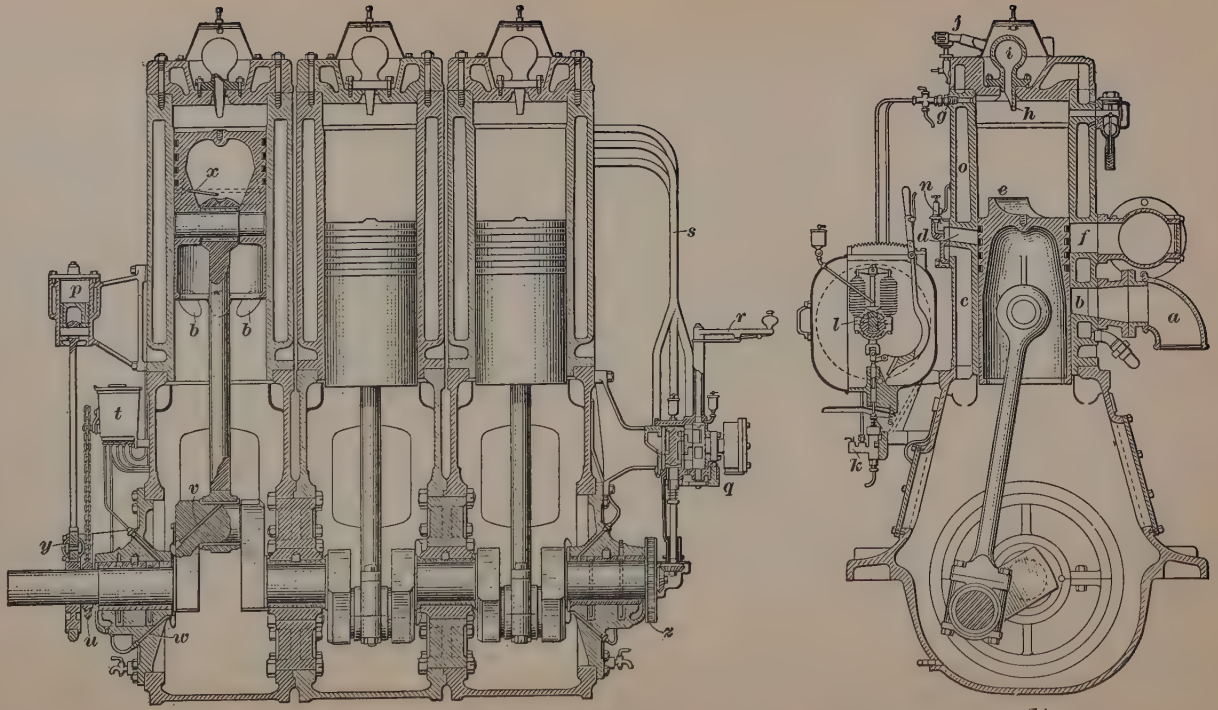

FIG. 44

engine is started, the ball is heated by the flame of a kerosene blow torch *j*, but after the engine has been running for a short time the blow torch is shut off, as the ball will be kept sufficiently hot by the successive explosions of charges in the cylinder. The position and shape of the lip *h* are such that the fuel, on striking it at a high velocity, is deflected and thoroughly mixed with the air in the cylinder.

87. The fuel used by the engine shown in Figs. 43 and 44 may be kerosene, fuel oil, distillate, crude oil or alcohol. Because of the cost, low-grade oils of from 24 to 30 degrees Baumé are preferable. The fuel is forced into the cylinder through the needle valve by a pump *k*, the stroke of which is varied by the governor *l* to suit the load on the engine. The oil from the pump is led to a distributing valve *m* by which it is sent to the needle valve of the proper cylinder at the proper time. The distributor is driven from the shaft of the governor by a bevel gear and pinion and rotates at the same speed as the crank-shaft. The time of ignition is controlled and the efficiency of combustion is regulated by the injection of water through the sight-feed valve *n* into the air that enters the cylinder from the crank-case. The water is taken from the water-jacket *o* surrounding the cylinder.

88. The engine shown in Figs. 43 and 44 is started and reversed by means of compressed air, which is stored in a suitable tank by the action of a compressor *p* driven from an eccentric on the crank-shaft. The reversing mechanism consists of a valve *q* controlled by a lever *r*. Pipes *s* lead to the separate cylinders from the reversing valve *q*, which is connected to the air-storage tank. The ports in the rotary distributing and reversing valve are so located and connected to the pipes *s* that when the lever *r* is thrown over in one direction, air will be admitted through the lower port of the valve and the engine will start in one direction; if it is thrown to the other side, air will be admitted through the upper port of the valve and the engine will start in the opposite direction. At the mid-position of the lever *r* the air is shut off completely

from the distributing valve. As the engine is of the two-cycle type, it will operate equally well in both directions.

89. Force-feed lubrication is employed on the engine shown in Figs. 43 and 44. A mechanical force-feed lubricator *t* is mounted on the engine frame and is driven by a chain from a sprocket wheel *u* on the crank-shaft. Pipes lead from the lubricator to the crank-shaft bearings and the other parts of the engine to which lubricating oil must be supplied. The crankpins are supplied with oil through ducts drilled in the crank webs, as shown at *v*, the oil being conveyed to a centrifugal oil ring, fastened to the crank, through the passage *w* from the pipe leading to the lubricator. A pipe conducts oil to a passage drilled through the wall of each cylinder in such a position as to register with the passage in the piston to which the pipe *x* is connected. At the bottom of the stroke, then, oil is injected through the pipe *x* and so finds its way to the piston-pin bearing. Oil rings on the main bearings in the end housings assist in the lubrication at these points.

90. The cooling water for the cylinder water-jackets is circulated by a reciprocating pump *y*, Figs. 43 and 44, the plunger of which is connected by a link to the eccentric that drives the air compressor. The governor shaft is driven by chain gearing from a sprocket wheel *z* on the end of the crank-shaft, an idler pulley being used as a tightener to take up the slack in the chain. Bevel gearing at the same end of the crank-shaft gives motion to the rotary distributing valve in the starting and reversing mechanism at *q*. The handle projecting from the top of the casing surrounding the governor *l* is used for varying the speed of the engine. It is connected by links to the plunger of the fuel pump and as it is moved along the notched sector the length of stroke of the pump is changed, thus altering the quantity of fuel injected and consequently the power and speed of the engine. This handle can be set so that no fuel will be injected by the pump, in which case the engine will stop.

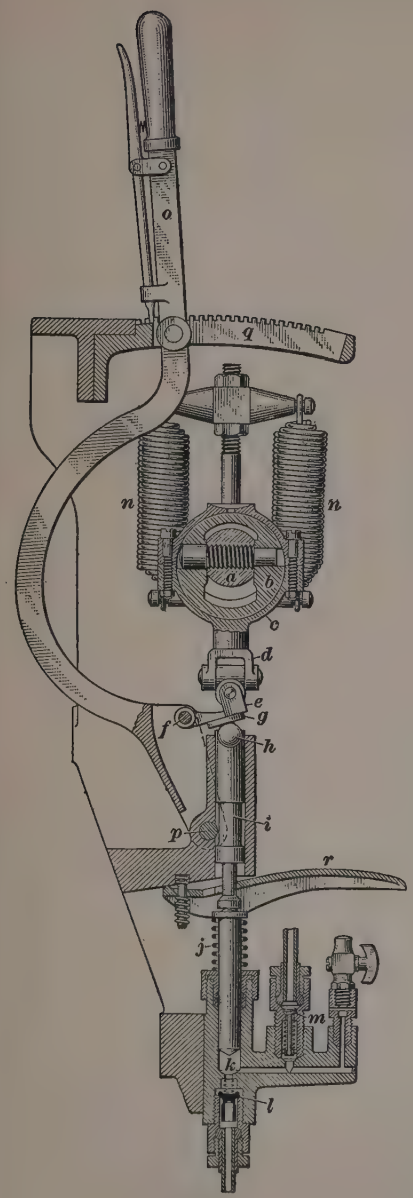

FIG. 45

91. The governor and fuel pump of the engine in Fig. 43 are shown in section in Fig. 45. The shaft *a* is driven from the engine shaft by chain gearing and carries an adjustable eccentric *b* surrounded by a strap *c* that is connected through the link *d* to a block *e* pivoted at *f*. The under face of this block rests on the flat disk *g* cast in one piece with the ball *h*, the latter fitting in a socket in the upper end of the pump plunger tappet *i*. As the shaft *a* turns, the eccentric *b* gives a reciprocating motion to the pump plunger. On the upward stroke the plunger is raised by the spring *j* and the partial vacuum formed in the barrel *k* draws oil in past the suction valve *l*. On the downward stroke the valve *l* closes and the plunger forces the oil out past the discharge valve *m* into the pipe leading to the cylinder.

92. The governor controls the speed of the engine by varying the stroke of the fuel pump and thus altering the quantity of oil sent to the cylinder. Weights attached to springs *n*, Fig. 45,

are thrown outwards by centrifugal force as the engine speed increases and the eccentric *b* is shifted on the shaft *a* so as to decrease its eccentricity or throw, thus decreasing the stroke of the pump plunger. The speed of the engine can be changed while the engine is in operation by moving the hand regulator *o*. This lever is pivoted at *p* and swings along a toothed sector *q*, thus limiting the stroke of the injection pump, and decreasing the amount of oil injected and, therefore, the speed of the engine. The handle *r* enables the pump to be worked by hand and oil to be delivered to the injection nozzles.

DOUBLE-ACTING TWO-CYCLE ENGINE

93. Cycle of Operation.—A vertical section through one cylinder of a double-acting two-cycle Diesel engine, taken at right angles to the crank-shaft, is shown in Fig. 46 (*a*), and (*b*) is a side view with one cylinder shown in longitudinal section. The fuel is injected into the cylinder by two separate fuel valves, one located in the cylinder head and the other in the cylinder wall below the lowest position of the piston. On the upward stroke, the air above the piston is compressed to a pressure high enough to cause the ignition of a fuel charge injected through the valve *a*, view (*a*), near the end of the stroke. The resulting combustion forces the piston downwards on a working stroke, at the end of which the gases escape through the ports *b*, which are uncovered by the piston. A moment later, scavenging air is admitted through the ports *c*.

94. The lower end of the cylinder, Fig. 46 (*a*), is closed by a stuffingbox *d* through which the piston rod passes. Thus, on the downward stroke, the air trapped below the piston will be compressed to a pressure of about 500 pounds per square inch. Just before the piston reaches the end of its downward stroke, a fuel charge is injected through the valve *e*. The pressure caused by the burning of this charge forces the piston upwards on a working stroke, at the end of which the piston uncovers the ports *b* and *c*, allowing the escape of the exhaust gases and the admission of scavenging air. Thus, each stroke of the piston is a working stroke on one side and a

compression stroke on the other. Obviously, the double-acting type of engine must have a crosshead, as a trunk piston cannot be used.

95. Because the cylinders of double-acting engines are closed at both ends, difficulties are experienced in keeping them properly lubricated and in cooling the pistons. The packing of the piston rods is subjected to both heat and pressure and must be renewed frequently to keep it from leaking.

The scavenging air required for driving out the remnant of the exhaust gases and filling the cylinder with a charge of fresh air is supplied at a pressure of about 4 pounds per square inch by electrically driven compressors, not shown in Fig. 46. The current for operating these compressors is supplied by auxiliary engines and generators used for operating winches and for other purposes while the ship is in port. The air for fuel injection is supplied by the four-stage air compressor *f*, view (*b*), which is driven from the forward end of the crank-shaft.

96. General Construction.—The bedplate of the engine in Fig. 46 (*b*) is composed of two uniform sections *g*, each supporting three working cylinders. These are bolted together at the middle of the engine, and a separate shorter section *h* is added at the end for the air compressor *f*. These castings are in the form of box-shaped girders flanged at the top and bottom and reinforced by ribs. The main bearings of the engine are supported by transverse girders *i* with bored boxes into which the cast-iron bearing shells are fitted. The bottom of the bedplate is closed by a light steel plate. The **A**-shaped frames *j* are bolted at the bottom to the bedplate flange and at the top to a casting *k*, known as the cylinder beam, that extends over the entire length of the engine and supports the cylinders. This beam is held to the frames by the tie-rods *l*, insuring a rigid construction.

97. The cylinder of the engine shown in Fig. 46 is composed of an upper and a lower half, a small gap *m* being left between them to allow free expansion of the sections. This

gap extends all the way around the cylinder, but not in one plane. Instead, as is clearly shown in (*b*), the gaps are slightly staggered, so as to decrease the tendency of the piston rings to catch as they slide over the openings. The upper half of the cylinder is cast integral with a flange *n* bolted to the top of the exhaust casting *o*. The lower half of the cylinder is cast integral with the lower cylinder head *p* and is bolted to the inner wall of the cylinder beam *k*. The water-jacket *q* is provided with baffle plates *r* and *s* that compel the water to circulate rapidly along the cylinder walls, and thus prevent scale deposits. The cylinder head *t*, which is water-cooled, fits into a recess in the top of the cylinder and is kept in place by the studs *u*, view (*a*). Owing to the absence of many valve pockets, the cylinder head becomes a light and simple casting. The only valve contained in the head is the fuel valve *a*, actuated by the push rod *v* from the cam-shaft *w*. The latter is located in front of the engine along the top of the cylinder beam and is driven by spiral gears *x*, view (*b*), from the crank-shaft, through an auxiliary vertical shaft *y*. Each cylinder has its separate fuel pump *z* actuated by eccentrics from the cam-shaft. The bearings a_1 that support the cam-shaft are bolted to the cylinder beam.

98. Cylinder Details.—The exhaust casting *o*, Fig. 46 (*a*), is bolted to the finished surface b_1 of the cylinder so as to form an air-tight joint, and the exhaust from all of the cylinders is carried to a common exhaust manifold. The scavenging-air casting c_1 is bolted to the finished surface d_1 on the opposite side of the cylinder. The gaps *m* between the upper and lower sections of the cylinder are situated approximately at the center of the exhaust and air ports. To prevent the escape of exhaust gases through the gaps into the air ports, and at the same time leave the cylinder halves free to expand, gas-tight joints are formed between the air and exhaust ports, as shown at e_1, view (*b*).

Each air port is provided with an automatic check-valve f_1, view (*a*), that prevents the inflow of scavenging air from the space g_1 into the cylinder until part of the exhaust gases have

escaped through the exhaust ports and the pressure in the cylinder has dropped below the pressure in the air space. The valve then automatically opens, to close again promptly when, soon after the beginning of the return stroke of the piston, the pressure in the cylinder exceeds that in the air space g_1. The check-valve, shown in detail in Fig. 47, consists of four light strips a of spring steel, held against the surface of

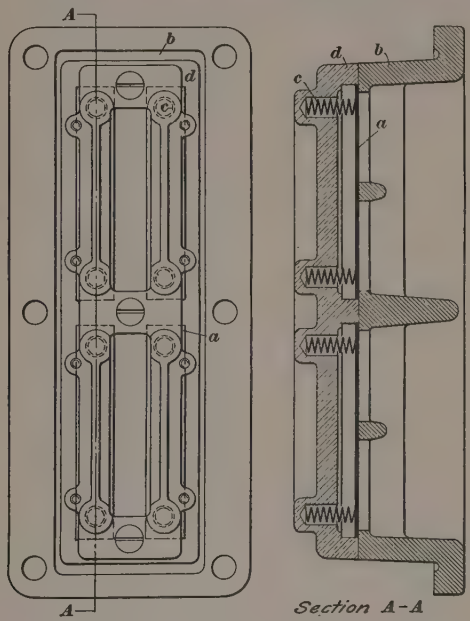

FIG. 47

the casing b by the pressure of the coil springs c in the cover d. As the four openings have a large combined area, only a small lift is required to insure the inflow of the needed volume of scavenging air. Leakage of compression from the cylinder around the piston rod is prevented by a water-cooled stuffing-box d, Fig. 46 (a). The cylinder head p, cast integral with its water-jacket, closes the lower end of the cylinder.

99. Piston and Crosshead Details.—As air is compressed both above and below the piston of a double-acting engine, the piston is made much shorter than that of a single-acting engine.

The guiding of the piston in the cylinder, ordinarily performed by the skirt, is done by the crosshead, which also takes the side thrust. As shown in Fig. 46 (*b*), the piston is fitted with two sets of rings, one set at each end, and is therefore made much heavier than the ordinary piston. Cooling water for the piston is delivered by a circulating pump to the crosshead pin h_1, through the non-corrodible telescoping tube i_1. The water passage j_1 through the pin is fitted with baffle plates, which cause the water to pass through the entire length of the pin before entering the passage k_1 in the piston rod. This is done in order to heat the water to a temperature high enough to make it safe to come in contact with the hot piston. A pipe l_1 inside the passage in the piston rod leads the overflow from the piston back to the crosshead, from which it passes out to a sump through the telescoping tube m_1. The crosshead shoes n_1 are faced with babbitt and slide on the water-cooled guides o_1 bolted to the frame of the engine.

100. Fuel Valve.—One cam on the cam-shaft w, Fig. 46 (*a*), operating the two rollers p_1 and q_1, is sufficient to time correctly the fuel injection for the upper and lower ends of the cylinder. The bell-crank r_1 turns freely on the shaft s_1 as a fulcrum. The arm t_1 is keyed to the shaft s_1 and connected to the rod u_1 by the link v_1. The end w_1 of the rod u_1 rests against the curved face of the upper end of the lever r_1. The other end is connected to the arm x_1, which is fastened to the shaft y_1 that operates the fuel-valve needle by means of a lever, not shown. When it is desired to change the lift of the needle, the shaft s_1 is turned slightly. This movement causes the end w_1 of the rod u_1 to be either raised or lowered along the curved face of the lever r_1, thereby changing the radial distance from the end w_1 to the fulcrum s_1. This slight variation in radial distance is sufficient to increase or decrease the travel of the rod u_1 and by so doing change the lift of the needle valve.

Owing to the very high temperatures developed in the cylinder of a double-acting engine, the expansion of the upper and lower sections of the cylinder may become sufficiently large

to cause the rollers p_1 and q_1 to separate from their cam. By properly adjusting the turnbuckles z_1 and a_2 so as to lengthen the rods u_1 and b_2, respectively, the levers r_1 and c_2 may be forced over sufficiently to reestablish contact between the rollers and the cam.

LARGE TWO-CYCLE DIESEL ENGINE

101. General Remarks.—The large two-cycle Diesel engine illustrated in Fig. 48 is of small cylinder diameter and long stroke. It is built in units of four, six, or eight cylinders for stationary or marine service. The engine is designed to run at approximately 116 revolutions per minute for stationary or twin-screw marine service, developing about 500 brake horsepower per cylinder; for single-screw vessels it is run at 90 revolutions per minute and develops about 400 brake horsepower per cylinder. A front view of the engine is shown in Fig. 48 and a section through one of the cylinders in Fig. 49. The cycle of events in the engine does not differ from that of the ordinary two-cycle single-acting Diesel engine, but in the construction several new features stand out. Chief among these are the construction of the cylinder, in which the cylinder head is replaced by a valve cage containing all the valves, and the arrangement of the scavenging-air pumps at an angle with the engine cylinders, as shown at *a*, Fig. 48. Another feature is that, instead of admitting scavenging air through ports in the circumference of the cylinder liner as is the common construction in two-cycle Diesel engines, scavenging air is admitted through a valve in the top of the cylinder. Fuel-injection air is supplied by a three-stage air compressor *b*, driven from the main shaft, and provided with intercoolers, such as that shown at *c*.

102. Construction.—The engine cylinders are mounted in pairs in a casting *a*, Fig. 49, to which they are attached by studs *b* that pass through the upper and lower flanges of the casting *c*. At the bottom each cylinder is left free to expand or contract longitudinally, so as to be relieved from any stresses set up by the difference in temperature of the inside

and outside cylinder walls. Each casting *a* is supported by **A** frames *d*, mounted on the engine bedplate *e*. Long tension rods *f*, each 6 inches in diameter, transmit the cylinder stresses, caused by the high pressures in the cylinders, from the casting *a* through the **A** frames to the bedplate, thereby relieving the cast-iron members of the engine of all tension stresses and in so doing decreasing the vibration of the engine. In addition, smaller horizontal steel tie-rods *g* are used at the bottom of the bedplate, close to each of the main bearings, to reduce the danger of bending the bedplate *e* by the pressures on the main bearings. Each pair of cylinders drives its own section of crank-shaft and is mounted on its own section of the bedplate. This feature enables the engine to be erected as a two-, four-, six-, or eight-cylinder unit, as desired. The crank-shaft sections are interchangeable, each consisting of two cranks set 180° apart and fastened to adjacent sections by flange couplings at the ends.

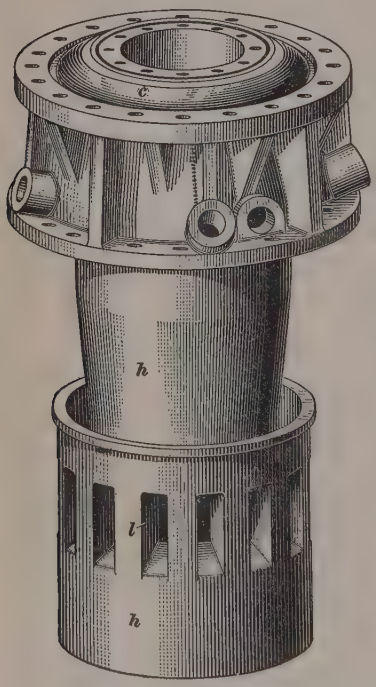

FIG. 50

103. Cylinder Details. The working barrel of the cylinder of the engine in Fig. 49 is a heavy liner *h* that at its upper end fits into the casting *c*, the upper end of the water-jacket *i* being formed between them. The lower part of the water-jacket is formed by a light cast-iron sleeve *j* secured at its upper end by the casting *c* and provided at its lower end with a water-tight joint *k* at the place where the sleeve surrounds the exhaust ports *l*. The exhaust ports are cast onto the bottom part of the cylinder liner, eliminating troublesome

corrosion due to a leaky joint between the cylinder and the exhaust ports. A perspective view of the cylinder liner and the casting *c* is given in Fig. 50.

104. Valves.—The opening in the top of the cylinder liner is closed by a water-cooled valve cage *m*, Fig. 49, which takes the place of the usual cylinder head. It contains the scavenging-air valve *n*; the fuel valve *o*, acting inside the tubular stem *p* that guides the scavenging-air valve *n*; the air starting valves, not shown; and an automatic relief valve *q* for relieving the compression pressure in the cylinder, as is sometimes necessary in starting or reversing. The shape of the scavenging-air valve *n*, and of the inside cylinder wall is such that the inrushing scavenging air must pass directly along the inside walls, absorbing a considerable part of their heat. This is of advantage, because the inside cylinder walls are cooled, and at the same time the temperature of the air that is compressed in the cylinder is increased, which aids the combustion of the fuel. The scavenging-air valve is actuated by twin rods protruding from the top of the valve cage. These rods are pushed downwards in unison by a pair of rocker-arms, not shown, that are operated by cams on the camshaft *r*. In moving downwards the valve spring *s* is compressed by a collar *t* that is fastened to the valve stem, and the valve is afterwards returned to its seat by the action of the spring. The bottom view of the valve cage, Fig. 51, shows the scavenging-air valve *a*, the fuel valve *b*, the automatic relief

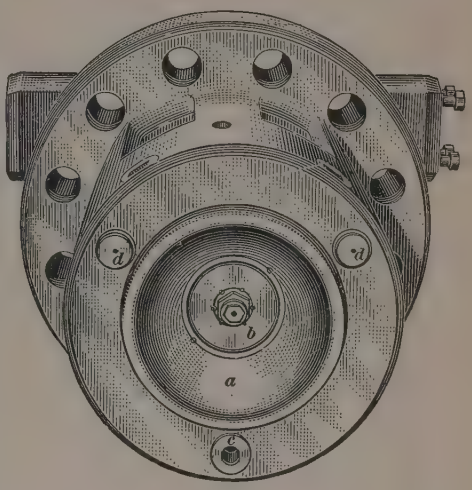

FIG. 51

valve c, and the two air starting valves d. Cooling water is circulated through the valve cage.

105. The tubular fuel valve stem p, Fig. 49, is fitted with piston rings u at the bottom to prevent gas leakage when the stem of the scavenging-air valve slides over the tubular stem in opening. The fuel valve is operated from the cam-shaft by a roller v and a system of rocker-arms w that transmit the motion of the roller to the valve pusher x. The linkage system operating the fuel valve includes a quadrant y fastened to the rocker-arm w and provided with a groove in which a link block z slides. A short link a_1 connects the link block z with the valve pusher x. By changing the position of the link block in the groove of the quadrant, by means of rods operated by hand from the operating station, the lift of the valve may be altered. The higher the link block z is placed in the quadrant y, the greater will be the duration and the amount of valve opening. This feature of manual control of the fuel-valve lift is useful for maneuvering purposes, as the amounts of fuel and injection air may be varied in this manner.

106. Piston.—The piston b_1, Fig. 49, has a removable hemispherical top c_1 made of forged steel. Piston cooling is accomplished by means of telescoping pipes. The outlet pipe d_1 extends almost to the top of the piston; but the inlet pipe, not shown, merely projects into the head. This insures a good circulation of cooling water, as the whole piston must be filled to the top before the water will overflow.

107. Scavenging-Air Pump.—The double-acting scavenging-air pump e_1, Fig. 49, is mounted at an angle to the engine cylinder and is driven from the main connecting-rod f_1, the crosshead guides g_1 of the pump being mounted directly in an extension of the **A** frames. Air is taken in through the screened openings h_1, admitted into the pump cylinder through the plate valve i_1, and discharged into the supply pipe j_1. The pump cylinders are made of light, close-grained cast iron and the pistons are made of aluminum bronze. The mounting of the pumps at an angle to the main cylinders has the

advantage of using less floor space. In addition, the height of the engine is not increased and there are no extra crank-shaft bearings necessary as in designs in which the scavenging-air pumps are driven from the crank-shaft. These features are important in marine service, where engine-room space is important.

108. Other Construction Details.—In the engine shown in Fig. 48, the motion of the crank-shaft is transmitted to the cam-shaft by a vertical shaft geared at one end to the crank-shaft and at the other end to the cam-shaft. The cam-shaft operates the fuel-oil pump by means of eccentrics. Each engine cylinder is supplied with fuel oil by an individual plunger in the fuel pump, and each plunger is driven from the cam-shaft by its own eccentric. The load control is made by varying the amount of fuel oil to each cylinder. This is done by varying the lift of the fuel-pump suction valves, which are under control of the governor. The governor is of the usual centrifugal type and is placed on the after end of the engine.

109. Lubrication.—A force-feed system of lubrication is employed for lubricating the main bearings, crankpins, crosshead pins, and crosshead shoes of the engine in Fig. 48. A lubricating pump, direct driven from the main engine, delivers the oil from an oil filter through a passage in the crank-shaft to the crankpin bearings k_1, Fig. 49. A passage in the connecting-rod f_1 registers with the hole l_1 in the crankpin when the crank is in its top position, and delivers oil to the crosshead bearings and the crosshead guides. The oil is drained from a reservoir in the bedplate and returned to the filter. Separate force-feed oil pumps are provided for lubricating the main cylinders, the main bearings, and the compressor cylinders. Grease lubrication is used for lubricating the valve gear.

110. Reversing Gear.—A feature in the reversing of the engine is that the same set of cams is used for both ahead and astern operation, the cam-shaft being turned by an air-operated reversing gear for the proper timing of the valves in either direction. Reversing of the engine is effected by manip-

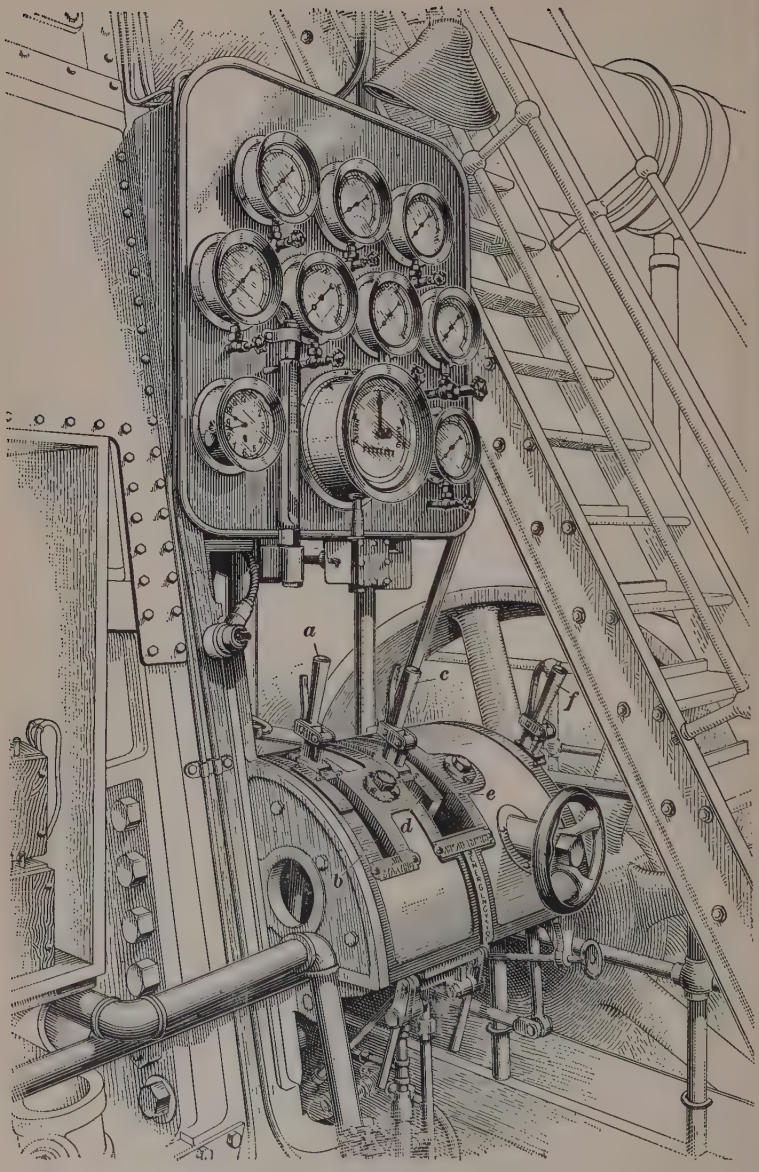

FIG. 52

ulating two levers in the operating station *d*, Fig. 48, placed at the end of the engine nearest the propeller, and shown in detail in Fig. 52. The lever *a* is used to start the engine. Moving the lever in the slot *b* away from the operator admits starting air to all the cylinders. As soon as the engine starts to turn over, fuel is admitted to the cylinders, the amount of fuel being controlled by the position of the fuel lever *c* in the slot *d*.

111. For ahead operation, the lever *c*, Fig. 52, must be placed in the left slot *d*. When combustion takes place in the cylinders, the supply of starting air is automatically shut off. The operator then gradually increases the amount of fuel supplied to the cylinders by moving the lever *c* away from him. If the engine is to be reversed, the lever *c* is pulled toward the operator, to the end of the slot *d*. This shuts off the fuel to the entire engine. Next, the lever *c* is moved to the right toward the slot *e*. This movement causes air to be admitted into an air cylinder, and the motion of the piston in the air cylinder is transmitted by a system of levers and gears to the cam-shaft, which is revolved so as to bring the cams into the astern position. This operation is completed when the lever *c* has reached the slot *e*. The lever is then moved forwards in the slot *e*, causing the engine to run astern as soon as the operator moves the starting lever *a* forwards in the slot *b*. The lever *f* controls the lift of the fuel valves so as to admit the proper amount of fuel and injection air for different speeds and loads, as previously explained.

MANAGEMENT OF MARINE GAS ENGINES

Serial 1869 Edition 2

INSTALLATION AND OPERATION

INSTALLING ENGINE AND AUXILIARIES

LOCATION OF PARTS

1. A common method of arranging the engine and accessory apparatus in a boat is indicated in the installation diagram shown in Fig. 1. While this is by no means the only arrangement, it will illustrate the relative location of the various parts. The parts shown in the diagram are: the shaft log *a*, stern post *b*, dead wood *c*, compression coupling *d*, sea cock *e*, muffler *f*, gasoline-supply tank *g*, engine exhaust pipe *h* leading from the engine to the muffler *f* and connected up by means of two unions *i*, and an elbow, a petcock *j* at lowest point in pipe, battery *k* and spark coil *l*, view (*b*), outboard gasoline-supply pipe *m*, view (*a*), from supply tank *g* to carbureter *n*, view (*b*), reverse rod *o* for forward, or bow, control, consisting of a galvanized-iron pipe with ends shaped for connection to reverse-gear mechanism and to lower end of reverse lever, which is held in the bracket *p*, regular reverse lever *q* in bow of boat, which can be removed from its usual position *q'* on gear-case *r*, air pipe *s* leading to whistle tank *t* to which the signal whistle is attached, brass strainer *u* on outlet pipe in gasoline tank, hand wheel *v* for operating valve in gasoline-supply pipe, and brass tank plate *w* provided with two small vent holes.

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2. To install a marine gasoline engine so as to insure maximum safety and freedom from excessive vibration necessitates a thorough understanding of all the requirements to be met, including the construction and location of the fuel tanks, engine, carbureter, piping, etc., and also a thorough knowledge of the operation of the engine. Before any attempt is made to install the engine, there should be provided a working blueprint or drawing, indicating the distance from the center line of the crank-shaft of the engine to the under side of the bed or lugs, giving all the dimensions and showing plainly the outline of the base below the bearing side of the lugs. A drawing of the longitudinal and athwartship, or crosswise, pieces, with the dimensions plainly marked, should accompany the drawing of the engine base.

INSTALLING THE ENGINE

3. Location of Engine.—For light speed boats, the practice is to install the motor aft of the center of the boat that it may help lift the bow out of the water when running. This lifting, or *planing,* reduces the skin friction, which is one of the principal hindrances to speed. The location of the engine is a matter which is largely governed by the purpose for which the boat is intended. No hard-and-fast rule can be given. In general it should be placed so that its weight will not seriously affect the normal trim of the boat. Placing the motor in the center of the boat helps to give a long propeller shaft and consequently less pitch to the engine. It also makes a handy arrangement for the tanks. By placing a tank on either side, the fuel feed is equalized no matter how the boat may roll.

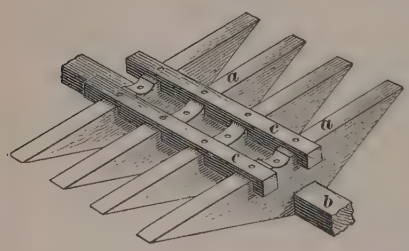

FIG. 2

4. One form of engine bed is shown in Fig. 2. First the cross-members *a,* which should be of sufficient size, are

fastened across the boat at about a distance of 12 inches from center to center. These pieces are fastened to the frames of the boat and lag-screwed or bolted to the keel *b*. They should be as wide from side to side as circumstances will permit and if possible should extend to the round of the bilge. The fore-and-aft timbers *c* are notched and lag-screwed or bolted to the athwartship pieces *a* as shown. If bolted, the fitting must be done before the crosspieces are laid.

5. Lining Up the Shaft.—When laying the engine bed, the first thing to do is to line up for the shaft. With the engine will usually be given the height the center of the flywheel should be placed above the bottom of the boat. If no height has been given, the distance from the center to the rim of the flywheel should be measured and 3 or 4 inches added for clearance from the bottom of the boat. An upright should be nailed to the bottom at the point where the face of the flywheel will come; this should be cut off at the height of the center of the wheel. The object of the clearance is to prevent the wheel, when revolving, from throwing about bilge water that may be in the bottom of the boat. The objection to too much clearance is that it is liable to give the engine too great a pitch. The engine should be as nearly level as possible, and in any case the pitch must not exceed 3 inches to the foot.

6. After the upright has been cut off, a nail should be driven into it in the exact center of the width of the boat. A string should next be passed through the hole in the shaft log and a stick tied to its outside end. The string should be pulled taut and its inside end fastened to the nail, close down; the stick drawn flat against the hole on the outside is then shifted until the string passes through the exact center of the hole. The top of the engine bed should be from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch lower than the engine is to be placed, and must run parallel to the string that passes through the shaft-log hole. The distance between the top of the bed and the string should be made equal to the distance between the under side of the engine and the center of the shaft plus $\frac{3}{8}$ inch.

7. Placing Engine on Its Bed.—The engine is next placed on the bed and the shaft run through the shaft-log boring and propped in position. The engine is then lined up with the shaft and wedges placed under the four corners to force it into position. The wedges should be of hard wood, about 6 inches or 10 inches long and tapered from $\frac{3}{4}$ inch to nothing. After the engine has been bolted to the bed, the shaft may be slipped in place and fastened. When nails or bolts are to be driven through the wedges, holes should be bored to prevent their splitting.

When placing the stuffingbox on the dead wood, care should be taken that it lies at perfect right angles with the shaft. If it does not, the dead wood must be cut into until the stuffingbox is at right angles with the shaft, or else, when the box nut is screwed home it will bind on the shaft. To know if all is well here the engine should be turned by hand with the petcocks open. With cylinders and bearings well oiled, the engine should now crank easily.

8. Propeller.—The propeller should be placed as close to the stern of the boat as is safe. By this is meant that enough clearance must be provided so that a bent blade will not hit and cut the stern. When a blade is slightly bent, it can be hammered back into place by laying it on a block of wood and having another piece of wood between the blade and the hammer. If much bent it should be sent to the maker, who will put it back into form. A blade that has been badly bent is liable to break off at any time when in use. The top of blades should be submerged 2 or more inches under the surface.

If the propeller turns in the direction of the hands of a clock when standing back of the stern and looking at it, the twist of the wheel in the water will tend to push the stern of the boat to the right, or starboard. If the propeller turns in the opposite direction, the push of the stern will be the opposite. The reason for this is that the water below is more solid than that at the surface, and offers greater resistance to the thrust of the blade. Because of this a boat turns in a smaller circle one way than the other.

Propellers will sometimes jar loose. They should be keyed on and a setscrew used, or a cotter pin placed through the end of the shaft.

9. Salt-Water Fittings.—Special fittings are required for use in salt water because bronze or brass near iron or steel in salt water sets up a galvanic action that will quickly eat away the iron. If a bronze propeller is placed on an iron shaft, this action will quickly eat away the shaft and cause the propeller to be lost. Iron pipes for the water circulation will soon choke with rust and will fill the passages in the water-jacket with rust. The bolts through the ground-joint pipes in the water circulation on either side of the water-jackets should be of brass or bronze. Iron bolts will readily corrode. There should be no iron or steel struts near any bronze or brass fittings. Stuffingbox and bolts should be of bronze, and also the shaft log if it is made of metal. There should be nothing whatever in the water circulation that is made of anything but brass or bronze. The interior of the water-jacket and the exterior of the cylinders are of such large construction that the corroding action is slow within them, but they should be cleaned out once a year.

FUEL TANKS

10. Shape of Tank.—For the storage of the gasoline, kerosene, or crude fuel oil, the tank required should be so constructed that it will retain the fuel under all weather conditions. For economy of space, tanks are usually made to fit into the bow, the bilge (side), or the stern of the boat. These tanks present large flat surfaces at their different sides, against which the 10 to 40 gallons of fuel that they contain deals heavy blows when the boat is in a seaway. In order to prevent the fuel from rushing from end to end of the tank and also to support, or stay, the sides and bottoms, transverse partitions, or **baffle plates,** are provided in the interior of the tanks. These should be open at the bottom to allow a free passage of the contents from one compartment to another. By

the use of these plates, the force with which the fuel strikes the sides and ends of the tank is greatly reduced.

11. A tank made in cylindrical form is superior to any other on account of its greater strength and the absence of flat surfaces to be pounded. The curves of the walls turn all rushes of liquid into glancing blows. However, it is better that even this style of tank be fitted with baffle plates, both as a matter of reducing strains and of stilling the noise of the swashing that goes on in undivided tanks during a seaway.

Flat-sided tanks should have boards flattened up against them and braced to help relieve the strain, or pressure, from the inside. They should also have a raised rim around the outside of the top edges, with a small pipe leading overboard to discharge gasoline from a spill or overflow. The superiority of the seamless cylindrical tank is demonstrated if the air-pressure feed-system is used, it being a difficult matter to keep the joints of a flat-sided tank air-tight on account of the surging of the fuel against them.

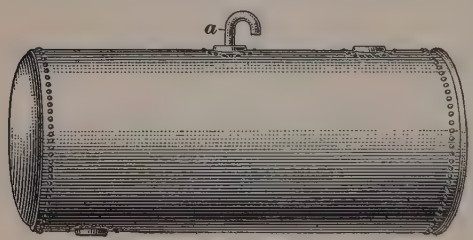

FIG. 3

12. Tank Vents.—A vent is necessary in a tank to admit air to supply the space vacated by the fuel that has flowed to the motor; otherwise, a vacuum would be created and the flow of fuel through the pipes be suspended. The vent should be placed so that it will not admit dirt or water. Perhaps the best method of venting is by means of a curved pipe opening into the top of the tank, as shown at *a*, Fig. 3. Air, but no dirt, can enter this pipe. Another good way is to force a hole through the screw thread just below the lower edge of the filling cap. Still another method is to pierce the top center of the filling cap with a very fine hole. In this case it is better during rain, fog, or spray, to cover the cap with anything handy. The hole must be only the size of a pin.

13. Materials Used.—Copper is the most common metal used in making tanks because it is not corroded by gasoline or oils. Steel tanks are also often used but these should be tin-lined, otherwise the action of the water at times found in gasoline will cause the interior to rust and deposit a sediment in the fuel that will be conveyed to the pipes and carbureter.

14. Cleaning the Tanks.—All tanks should have a draw-off cock placed at the lowest point of drainage for the purpose of getting rid of the sediment that is sure to find its way into them. When it is suspected that the tank has any foreign matter in it, the valve in the pipe line should be shut off and a receptacle placed under the drainage cock. The fuel should then be let off from the tank as quickly as possible, so that it will carry with it any dirt that may be inside. Gasoline poured through the tank will clean it still further. The fuel thus flushed out of the tank can be strained through a chamois skin and regular strainer, and then poured back into the tank.

15. Position of Tanks.—The ideal position for tanks is to have one on each side of the boat with a pipe leading from each to a main supply pipe for the carbureter. In this position, no matter how the boat is rolling, the supply to the carbureter remains constant. The bottom of the tanks should be at least 6 inches above the level of the float in the carbureter to insure a flow of gasoline to the engine. With a 6-inch elevation, the tank may be placed in any part of the boat with the assurance that even in a seaway there will be no serious results. The motor may run fitfully in a bad sea, but with either vaporizer or carbureter it will keep going if it is otherwise in good condition.

16. Care of Tanks.—All gasoline tanks should be painted on account of the corrosive action of salt water. While it is the common impression that copper will not corrode, it has been found that, if unrestrained, salt water will eat through $\frac{1}{16}$ inch of copper in two seasons.

If a leak develops, it can be plugged with common brown soap and painted with a thin coat of shellac. After this is dry, a second coat of shellac should be applied and then a piece of any kind of thin cloth that has been wet with shellac should be spread over the leak. This will make a very satisfactory temporary repair.

17. Air Pressure.—Sometimes it is necessary to place the gasoline tanks low down. This steadies the boat when properly placed, but it also necessitates a method of raising the fuel to the carbureter. The gasoline is usually forced to the carbureter by means of air pressure derived from a hand pump. The pump is connected to the tank by a pipe and the gasoline is thus kept under the necessary pressure. The tank and pipes in this system must of course be perfectly air-tight. Joints can be made air-tight by the use of hot sealing wax, and small leaks in the top of the tank may be taken care of by using shellac.

If air pressure is used, a small auxiliary gravity tank situated near the motor is almost a necessity. With it one is in a measure independent of the air pressure, should it fail either by the air pipe becoming obstructed or because of leaks. In case of such an accident, the auxiliary tank can be kept supplied by drawing from the main tank by siphoning, or by inserting a small pump into the tank, or dipping from it through the cap opening.

18. Tank Indicators.—In any tank, the outlet pipe should be placed about $\frac{1}{2}$ inch above the bottom of the tank so that sediment will not flow into it. The amount of gasoline that a tank contains at any time may be ascertained by means of a measuring stick, which can easily be made for any tank. When making such a stick, fuel should first be poured into the tank until it begins to run out of the cock in the pipe line; it should then be poured in 1 gallon at a time. After pouring in each gallon, a smooth stick should be inserted to the bottom of the tank and notched where the level of each gallon of fuel comes. This stick can then be used for finding the quantity of fuel in the tank at any subsequent time. Many of the

cylindrical tanks are supplied with indicators that automatically tell the quantity within. Gauges for this purpose are also made. They should not be placed in the pipe line for the reason that if anything happened to the gauge the supply of fuel would be cut off.

19. A gasoline tank depth gauge, or indicator, for showing the depth of gasoline in the supply tank, is illustrated in Fig. 4. A float *a* rests on the top of the gasoline and rises and falls with it. A slot in the center of the float engages with a twisted flat stem *b*. As the float rises, this stem is moved around and carries with it a hand, or pointer, *c*, which moves over a dial graduated to indicate the quantity of gasoline in the tank. Rotary motion of the float *a* is prevented by the frame *d*, with which lugs at the edge of the float engage.

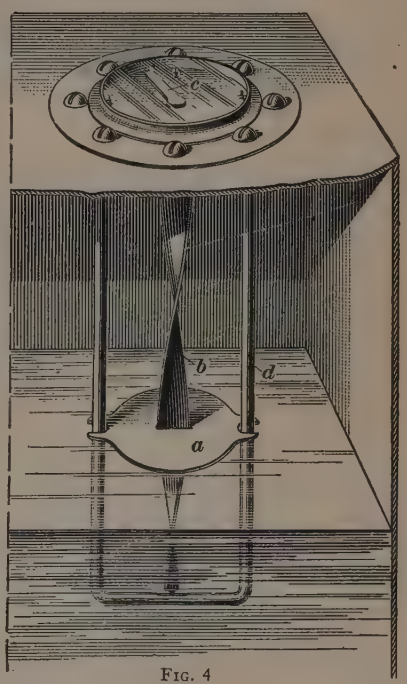

FIG. 4

20. Filling a Tank. To fill a tank with fuel, a strainer funnel provided with a fine wire mesh or an ordinary funnel with a piece of chamois skin spread over it should be used. Before removing the cap from the tank, the dust should be brushed or blown from it. The cap should be laid down bottom up, so that it will not pick up dust on its edges and thus get dirt into the fuel. If the tank is new, it should be flushed thoroughly before being filled.

The capacity of a tank should be enough to run the engine at least 20 hours. The supply can be figured for any engine

from the fact that a two-cycle engine generally uses about $1\frac{1}{4}$ pints of gasoline per hour per horsepower, and a four-cycle engine, about $1\frac{1}{8}$ pints per hour per horsepower.

GASOLINE PIPE LINE

21. The pipe line should leave the tank with a spiral of two or more coils twisted into it for the purpose of taking up vibration from the motor and shocks from the waves. Coils should also be twisted into the pipe line wherever it is joined to any part that is fastened to anything stationary, the reason being that every boat buckles or vibrates more or less in a seaway and unless the pipe can give and take, it is liable to be snapped. When pipe lines are not fitted in this way, it is necessary to carry an extra length of pipe with nipples fitted on the ends for use in case of accident. If other tanks are in use the pipes from them should be brought to the main line pipe.

22. Fuel Strainers.—A fuel strainer should be set in the main pipe line for the purpose of catching any dirt or water that may be in the gasoline. The strainer should be opened frequently, say, every eight or ten runs, to clean the fine-wire mesh. Sometimes, when oil is mixed with the gasoline in the tank, the fine mesh of the strainer gathers a gum-like substance that in time clogs enough to stop the flow of fuel. The catch of water may easily be run off by a turn of the cock at the bottom of the strainer. Frequent cleaning of the strainer will prevent the corroding of its screens. With all precaution and care the strainer will occasionally become damaged; when it does a short piece of pipe should be inserted in the place occupied by the strainer. If the gasoline is properly strained before being poured into the tank, the probability is that the flow will continue for many trips without trouble.

23. Placing the Pipe Line.—The pipe line should not be laid where it can be trodden upon, as it may be flattened, or broken, for the finely drawn pipe is fairly brittle. If necessary to bring it across the floor it should be run in a corner or

covered the same as electric wires are covered when on the outside of walls. Leaks in the line can easily be treated with shellac, the best shellac being that which has coagulated a little in the bottom of a bottle or box.

The pipe line should be of copper, and should not be run under floors, or in out-of-the-way or inaccessible places. It should be renewed every 2 or 3 years, because it crystallizes under the constant vibration. It also may corrode in spots under the action of salt water. If it clogs, the fuel should be shut off and the pipe disconnected. It can then be blown out with an air pump, or a long wire can be run through it. It is well to have all pipes as short as possible. Ground joints in the line are more easily handled than threaded ones. Ground joints are smooth-ended and are drawn together by the use of box-like nuts.

A rubber section should never be installed in the gasoline pipe line, because gasoline is a solvent for rubber and the rubber will be carried into the piston and rings. The gasoline supply pipe should be of good size so that it will not become obstructed easily.

LOCATION OF CONTROL LEVERS

24. Control Levers on Engine.—In many boats, especially the smaller and less expensive ones, the levers for controlling the time of ignition and the throttle valve are located on some part of the engine, within easy reach of the operator. The direction in which to move the spark lever to alter the ignition timing or the throttle lever to alter the position of the throttle valve is given in the instruction book sent out by the maker of the engine. When one does not know the direction in which to move them, and the instructions of the maker are not at hand, this information may sometimes be obtained by inspection. For instance, in order to advance the spark, it is necessary to rotate the movable part of the timer in a direction opposite to that from which the timer rotor is turning. In like manner, the spark is retarded, or made to occur later, by moving the lever in the same direction in which the rotor turns. These directions apply to timers,

but in the case of magneto ignition, where the spark time is varied by moving some part of the magneto interrupter, it is more difficult to determine the direction in which to rotate the lever. One should not attempt to start an engine until he is sure that the spark is retarded; otherwise, serious injury may result.

In some makes of carbureters it is possible to tell by inspection when the throttle valve is open and when it is closed.

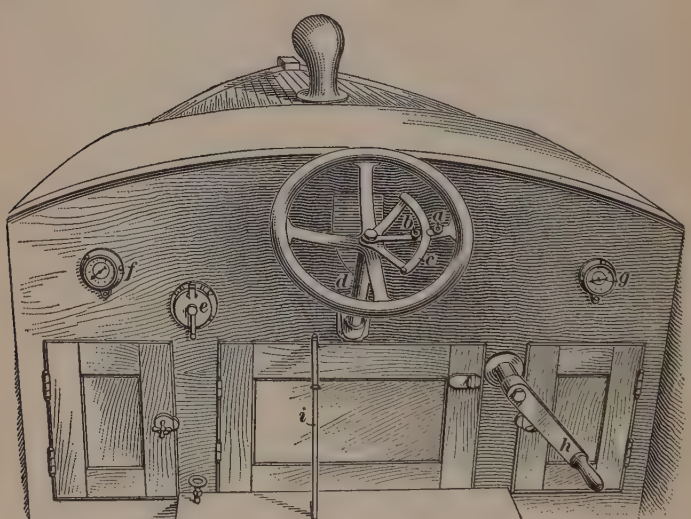

FIG. 5

However, by attempting to start the engine with the throttle lever in different positions, the open and closed positions may be ascertained.

It is always the best plan, especially for the novice, to follow the maker's instructions or get the information from some properly informed person in the vicinity and thus clear away any doubt as to how to obtain the desired results.

25. Bulkhead Control.—In a large number of boats, the throttle valve and timer are operated from levers located on the bulkhead, forming the **bulkhead control.** This form of control is made possible in the modern boat with its

engine well forwards and the bulkhead between the motor and the helmsman. The switches and push buttons are fastened on the bulkhead within easy reach of the operator and are wired to the battery or magneto, or to both where a double or dual system of ignition is found. The levers are sometimes fastened to the bulkhead in the place most convenient to the steering wheel and a system of rods and levers lead to the timer or magneto and to the carbureter, or they may be located on top the steering wheel With the latter arrangement, the control rods are brought up through the hollow steering-wheel shaft. Sometimes the levers are located under the steering wheel.

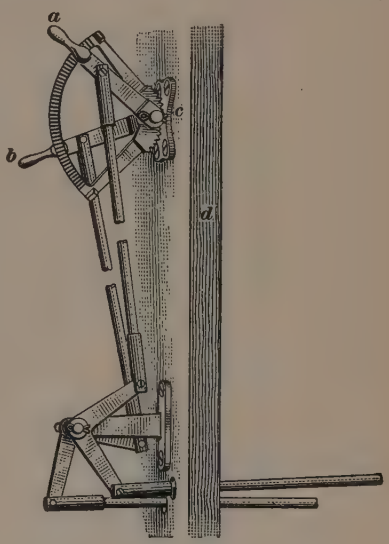

FIG. 6

26. In Fig. 5 is shown a bulkhead control arrangement in which the control levers are located on the steering wheel. The throttle lever *a* and the spark lever *b* are arranged on a quadrant *c*, around which they may be moved. They are connected to the timing device and the carbureter by means of rods passing down through the shaft *d* of the steering wheel. The switch *e* and gauges *f* and *g* are located on the bulkhead within easy reach of the steering wheel. A starting crank for the purpose of turning the engine over by hand when starting, is located at *h*, and the reversing-gear lever at *i*. This is a very convenient arrangement and one that is coming more and more into use. The bulkhead control is also sometimes employed where the engine is located aft of the cockpit, in which case the levers and rods must run aft of the steering wheel instead of forward.

27. In some cases of bulkhead control the spark and throttle levers are arranged so that they must be moved up or down in order to operate the throttle valve or the timer. Such an arrangement is shown in Fig. 6. The levers *a* and *b* are carried on the bracket *c* and are connected to the throttle valve and timer by means of the rods and bell-cranks as shown. In this construction, the rods pass from the bell-cranks, through the bulkhead *d*, directly to the devices they are meant to operate.

Another system of levers and rods is shown in Fig. 7, where the rod *a* from the lever *b* passes through the bulkhead to a bell-crank *c*. From this bell-crank a second rod *d* passes to

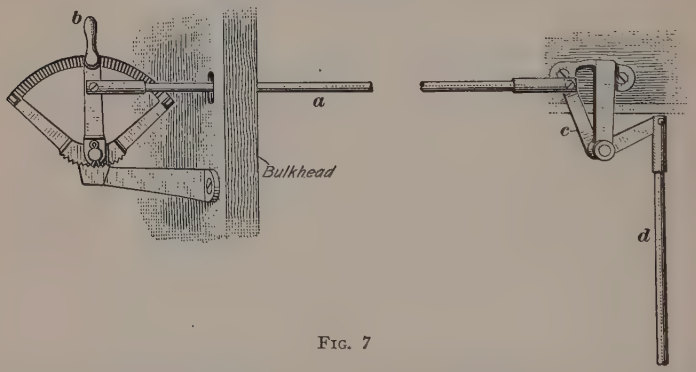

FIG. 7

the throttle valve or timer. In both Figs. 6 and 7 the control levers are located directly on the bulkhead and not on the steering wheel.

28. When installing the rods for a bulkhead control, the greatest care must be exercised to see that there is but little lost motion. Some lost motion cannot be helped but it must be small. Rods for the purpose of connecting the levers to the different parts, to be satisfactory, should be fitted with ball-jointed adjustable ends. With this type of rod the length can be regulated to a nicety.

When attaching the rods to the spark, be sure at the time of connecting that the spark is half way between full advance and full retard. In like manner the throttle should be connected when it is half way between full open and full shut.

CIRCULATING PUMPS

29. Plunger Pump.—A type of water-circulating pump used extensively on marine engines, and especially on the smaller sizes, is the plunger pump, one form of which is shown in section in Fig. 8. In this pump, the water is forced through the cooling system by means of the hollow piston or plunger *a*, which is driven backwards and forwards in the barrel *b* by means of the eccentric *c* surrounding the crank-shaft *d*. Check-valves *e* and *f* prevent the water from flowing back into the inlet pipe *g*. As the plunger moves forwards toward the crank-shaft, the suction thereby created lifts the check-valve *e* from its seat and draws water into the barrel. On its return

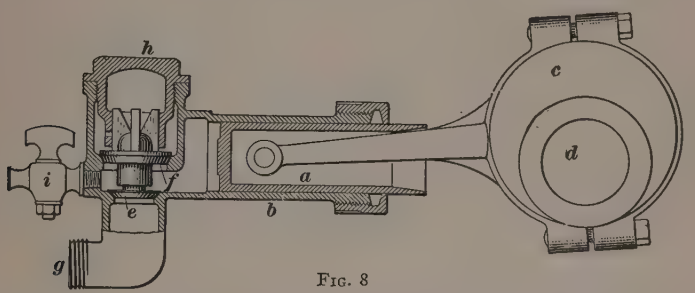

FIG. 8

stroke, the plunger forces the water through the check-valve *f* into the passage that leads to the cylinder jacket.

During the backward stroke of the plunger the check-valve *e* prevents the water from escaping back into the pipe *g*; and during the forward stroke, the valve *f* prevents the water from being drawn from the jacket space back into the pump. The check-valves may be taken out by removing the plug *h*. The cock *i* is for the purpose of draining the water from the pump barrel.

30. A form of single-acting pump used on an oil engine for the circulation of cooling water as well as lubricating oil is shown in section in Fig. 9. The body *a* of the pump is bolted to a supporting bracket *b* by the three bolts *c*. The plunger *d* is given a reciprocating motion through the link *e*, which is connected to an eccentric strap working on an

eccentric on the engine shaft. The valve *f* is the suction valve and the valve *g* the discharge valve. When the pump

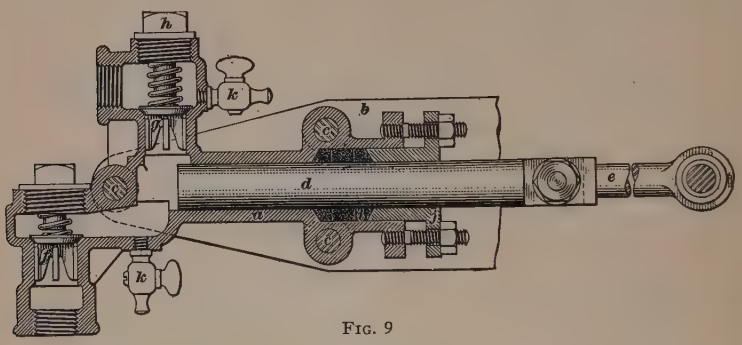

FIG. 9

is to be started for the first time, or after a long shutdown, it will need to be primed. To do this it is necessary to remove the plug *h,* lift the discharge valve, and fill the pump and piping with water. Hemp packing or candle wick saturated with oil is used to pack the plunger at *i,* being compressed by the gland *j*. The petcocks *k* are used to test the action of the pump. If water is emitted in pulsations when these cocks are opened, the pump is operating properly.

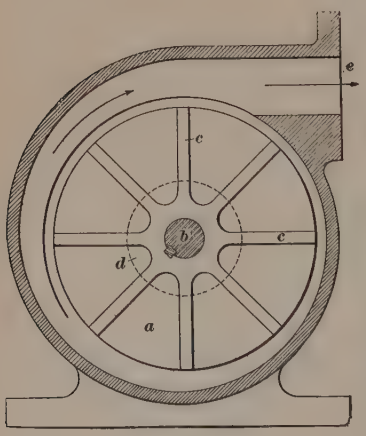

FIG. 10

31. Centrifugal Pump. Another type of water-circulating pump used quite extensively is the centrifugal pump, which operates on the principle shown in Fig. 10. In this pump the only moving part is a bronze or aluminum disk *a,* keyed on a shaft *b,* and on one face are cast blades *c,* which may be radial, as shown, or bent backwards. The shaft carries the disk *a* at one end, and works through a stuffingbox to prevent leakage. The water enters the pump through an opening indi-

cated by the dotted circle *d*. This inlet is on the side of the pump toward the observer, and, therefore, cannot be seen in the illustration. As the water enters the pump, it meets the blades *c* and is carried around and thrown outwards by centrifugal force, being expelled at *e*, provided the passage outside the pump is open.

32. It is not necessary that either the disk or the blades have a water-tight fit in the casing, because the pump simply establishes a difference in pressure between the points *d* and *e*, Fig. 10, but does not positively force the water. Consequently, if the flow is obstructed for any reason, the pump can still be revolved without injury to itself. Moreover, this type of pump does not lose its efficiency through wear. The pump is run at quite a high speed, generally about twice the speed of the engine; and if the resistance to circulation is not too great, it will throw quite a large stream of water. It is usually mounted on the crank-case of the engine and geared to the cam-shaft or to the two-to-one pinion.

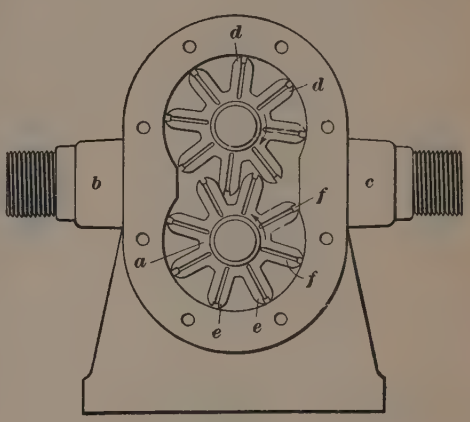

FIG. 11

33. Gear-Pump.—A type of pump used to some extent for circulating purposes is the gear-pump shown in Fig. 11. It operates equally well in either direction. One of the two gear-shaped pump members *a* is driven by a shaft and rotates the other with it. If the direction of rotation is that shown by the arrows, the water will enter at *b*, and pass out at *c*, being carried around by the outer teeth *d* and *e* and expelled as the teeth come together. The particular pump shown has

grooves *f* in the sides and tips of the teeth, which, it is claimed, prevent to a large extent leakage past the teeth, and thereby increase considerably the efficiency of the pump.

EXHAUST CONNECTIONS

34. Exhaust Pipe.—The larger an exhaust pipe is, the better the engine will work and the more power it will develop. There should be but few bends in it and these should be at as large an angle as possible. Every 45° elbow gives a resistance equal to the friction of 15 feet of pipe. The passage of water through the exhaust pipe reduces the speed of the boat somewhat, but it is necessary for the purpose of keeping the pipe cool. The exhaust should not pass near a fuel tank, even though the pipe is covered with asbestos. Accidents to the covering of the pipe may occur and consequently there is danger of fire or an explosion.

35. Underwater Exhausts.—Marine engines are cooled by the circulation of water through the water-jacket of

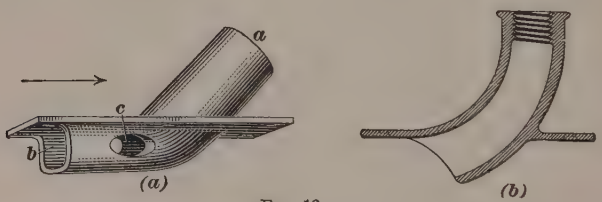

FIG. 12

the engine cylinder. A pump attached to the engine draws water through the bottom of the boat, sends it to the engine, and finally discharges it overboard, usually by way of the exhaust pipe, which is sometimes led under water, discharging through a special fitting, one form of which is shown in Fig. 12 (*a*).

The exhaust enters the fitting at *a* and leaves at *b*, under the water, the boat moving in the direction of the arrow. On account of the velocity of the boat, water rushes into the openings *c*, into the exhaust pipe, and out with the exhaust at *b*. This arrangement tends to increase the velocity of the

exhaust and reduce the back pressure on the engine. Another form of exhaust nozzle is shown in section (*b*). This form resembles that shown in (*a*), except that the passage *c* is omitted. Such devices are known as *underwater exhausts*, or *submerged exhausts*. Their purpose is to reduce the noise of the exhaust and to carry the gases under water, where their odor will not be objectionable.

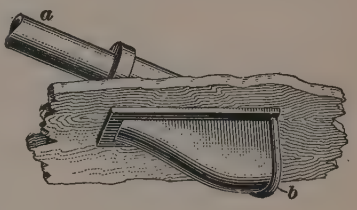

FIG. 13

36. Another type of underwater exhaust is shown fitted to the side planking in Fig. 13. The exhaust gases from the engine enter through the pipe *a* and escape into the water by way of the outlet *b*. The suction of the water as the boat moves ahead serves to draw the gases out and to relieve any back pressure. In Fig. 14 (*a*) is shown

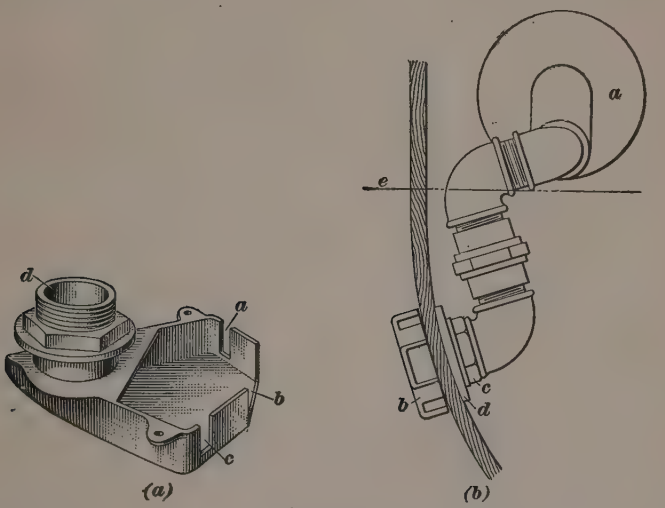

FIG. 14

an underwater exhaust containing three outlets, *a*, *b*, and *c*. The gases enter through the inlet *d* and are deflected toward the outlets and allowed to escape into the water. This device is shown installed in a boat, together with an expansion cham-

ber in (*b*). The expansion chamber *a* is simply a cylinder into which the exhaust gases from the engine are led and allowed to expand before entering the exhaust header *b*. The header, or underwater exhaust, is held in place to the outside of the side planking by the locknut *c*. Rubber packing is placed in the header against the outside of the boat and a wooden washer *d* is placed on the inside of the planking under the locknut, in order to prevent water from leaking into the boat around the threads under the nut. The water-line is shown at *e*.

The expansion chamber *a* and exhaust header *b* are connected up by means of elbows and a union, so as to form a sort of universal joint that will prevent the pipe from breaking in case of vibration of the boat. It is essential that some provision of this kind be made in piping connections on a boat, because the distance between any two separate parts so connected does not remain exactly the same, but varies on account of the vibration caused by the movement of the boat.

37. In using the underwater exhaust, it is customary to have the exhaust make its exit at some point just on the water-line. Then, when the boat is under way and begins to gather speed the stern will settle and submerge the exit. Directly at the stern center is not a good position on account of the dragged water flowing directly against the stern instead of away from it. This dead water, as it is called, may be detected by dropping a piece of cotton waste on the surface of the water an inch or two from the stern and observing its action. A better place for the exhaust is on the side of the stern where a strong current is sure to carry the exhaust away instead of pushing it back.

38. With the exhaust under water at all times it is often hard, if not impossible, to start the motor because of the resulting back pressure. On many boats using the underwater system of muffling it can be readily demonstrated by having some people stand near the exit of a water-level exhaust, that the sinking of the exhaust several inches below the surface will materially slow down, if it does not entirely stop, the engine.

The exhaust pipe is sometimes installed at an upward angle from the muffler to the point of exit. This renders the muffler liable to become partly filled with water when a sea rises well above the opening. It is better practice to carry the pipe in an arch, or even at a slight angle, downwards to the point of exit and thus prevent the inflow of water.

39. Mufflers.—A muffler, or silencer, is a device used for deadening the noise of the exhaust gases as they escape into the atmosphere at the end of the working stroke of a gasoline engine. The sound is deadened, or muffled, by leading the gases into a chamber where they are cooled somewhat and allowed to expand so that the pressure at which they enter the air will be reduced. Mufflers constructed for marine

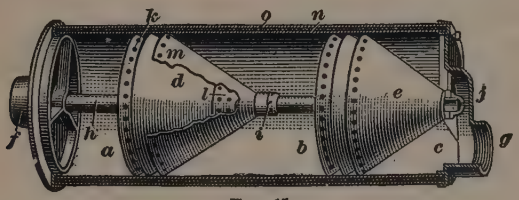

FIG. 15

engines are known as wet and jacketed mufflers; or, the construction may represent a combination of both of these types.

In the *jacketed muffler,* water from the cylinder water-jacket outlet is allowed to circulate around the outside of the muffler, to assist in cooling the gases and thereby reducing their volume. The *wet muffler* is one in which all or a part of the exhaust water from the water-jacket is discharged into the engine exhaust, where it is turned into steam, cools the exhaust gases, and combines with them, increasing their density and sluggishness, and thereby muffling the exhaust. The water from a jacketed muffler may be diverted into the exhaust itself, to further reduce the sound of the exhaust, this being the combination system already mentioned. The wet and combination mufflers are the most common types used in marine service.

40. A typical marine engine muffler is illustrated in Fig. 15, which is a sectional view showing the interior arrangement.

This muffler comprises three expansion chambers *a*, *b*, and *c*, separated by two sets of conical baffle plates *d* and *e*. The exhaust gases and waste water from the cooling system enter the muffler by the inlet opening *f* and pass out through the outlet *g*, which is placed low in the outlet head to provide a means of escape for any surplus water that may accumulate. A part of the gases entering the muffler passes directly into the chamber *a*, while the remainder passes through the axial tube *h*, some escaping by means of the holes *i* into the middle chamber *b* and some going clear through the tube and out of the nozzle *j*.

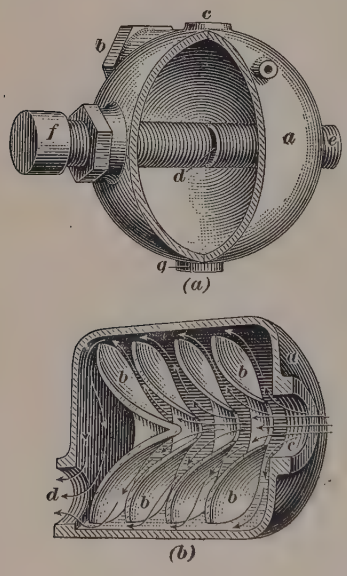

FIG. 16

41. The cones that separate the expansion chambers are perforated at top and bottom, so that the gases that enter the chamber *a*, Fig. 15, pass through the holes *k* in the first cone, *l* in the second cone, and *m* in the last, into the chamber *b*. The gas passing out of the nozzle *j* at high velocity creates a vacuum in the chamber *c*, so that the gases move rapidly into it from the second chamber *b* by way of the holes in the conical baffle plates *e*. This rapid forward movement of the exhaust gases through the first and second chambers to the third, causes a sudden expansion, removing the heat from the gas and reducing the pressure in the muffler, so that the gases escape into the atmosphere without any noise.

The walls of the muffler consist of an inner layer *n* of heavy material and an outer metal covering *o*, separated by a layer of asbestos, so as to prevent metallic sound from the gas impinging against the walls. To secure best results the asbestos used should be wire-woven.

This muffler is designed for use where the water is run into the exhaust pipe near the engine. Some mufflers are made with a separate water inlet located in the same end that the gas inlet opens into.

42. Two types of marine engine mufflers in which the water mixes with the exhaust gases are shown in Fig. 16. In view (*a*) is shown a silencer consisting of a spherical shell *a*, into which the exhaust gas passes by way of the inlet *b* and the water by way of the opening *c*. The gases expand in the shell, and become cooled by contact with the water, after which they enter the exhaust outlet at *d* and pass out at the opening *e*. The opening for the exhaust outlet in the center of the chamber is adjustable by screwing in or out the long nipple *f*. The larger portion of the water passes out of the drain *g*, a small portion being taken out with the exhaust gas. The location of the exhaust inlet with the water inlet directly in the path of the entering gases gives the water and gases a circular motion, allowing the gas to cool and expand and reducing the pressure.

43. In Fig. 16 (*b*) is shown a muffler that consists of the cylinder *a* fitted with deflecting plates *b*. The exhaust gases and circulating water enter the cylinder at *c* and escape by way of the opening *d*. Part of the exhaust gases passes through the holes in the center of the baffle plates and part passes between the edges of the plates and the wall of the muffler, as shown by the arrows. The deflecting plates break up the force of the incoming gases and allow them to expand, thus reducing the pressure and allowing the exhaust to pass into the atmosphere without noise.

44. When a muffler is used, the power of the engine is reduced to a slight extent due to the back pressure produced by the additional friction of the muffler. On account of this, it is a good plan to have the engine fitted with a muffler cut-out, or two-way exhaust, by means of which the engine may exhaust into the open air when occasion permits. The boat may be started more readily by this means and when running in localities where the laws permit it, the muffler may be cut out and the maximum power obtained without increasing the wear

on the engine. An increase of power is obtained in speed boats by doing away with the manifold, or common exhaust pipe, and having a separate pipe for each cylinder. Where facilities are at hand to make the change, additional power can sometimes be obtained by leading the exhaust from each cylinder to one common pipe of larger dimensions, the opening to which is aft of the last cylinder.

REVERSING GEARS

45. In the handling of motor boats, it is often desirable to back the engine or turn the propeller in a direction opposite to that for going ahead, even when there is only one set of

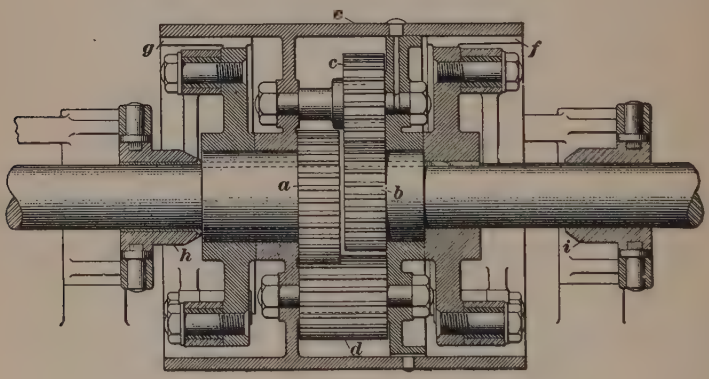

FIG. 17

gears for forward speed, and hence no speed-change device. In such cases, it is desirable to have a device by means of which the direction of motion of the propeller shaft may be reversed while the engine runs continuously in the one direction, which is usually the case with four-cycle engines. The reverse motion of the propeller is sometimes needed to check the speed of the boat, to bring it to rest, or to run the boat astern.

There are several forms of reversing mechanisms, but they are similar in principle so far as the motion of the engine and propeller shaft is concerned, differing only in the method of making the connections for the reversal of motion. In some

cases, spur gears and clutches are used; in others, spur gears and sliding feathers; and in still others, bevel gears.

46. In Fig. 17 is shown a reversing gear that depends on friction clutches for its operation. The propeller shaft is divided into two parts, the one, connected to the propeller, carrying the gear *a*, and the other, connected to the engine, carrying the gear *b*. The gears *c* and *d* mesh with these gears. The gear *b* is slightly smaller than gear *a*, and *c* meshes with *b*, and *d* with *a*. Another gear similar to *c*, but not shown, meshes with *d* and *b*, while one similar to *d* meshes with *a* and *c*. The gears *c* and *d* run on pins that are held in place in the web of the drum *e*. There are two friction clutches *f* and *g*, the latter serving to hold the drum *e* stationary when the movement of the propeller shaft is to be reversed. To reverse the motion of the propeller shaft while the engine is running, the spreader *h* is thrown inwards by the reverse lever, so that the clutch *g*, which is stationary, grips the drum *e* and holds it. The pins on which the gears *c* and *d* revolve are thus also held stationary, and the relative motions of the gears are as shown diagrammatically in Fig. 18. The crank-shaft transmits motion to the gear *b*, in the direction indicated by the arrow. The gear *c* in mesh with *b* turns in the opposite direction and transmits motion through a long gear *c'*, not shown in Fig. 17, to the gear *a* on the propeller shaft, which is thus made to move in a direction opposite to that of the gear *b* on the end of the driving shaft. The gear *b* is also in mesh with the gear *d'*, which turns gear *d* in the same direction as that in which the gear *c'* moves, and hence helps to turn gear *a* in a direction opposite to that in which the driving gear *b* moves. The gears *d'* and *d* are duplicates of the gears *c* and *c'*, each pair transmitting a portion of the power when the lever is reversed. When the reverse spreader *h* is thrown out of engagement and the forward spreader *i* is thrown in, the same movement of the reverse lever serving to accomplish both

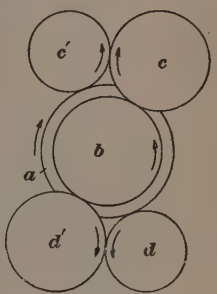

FIG. 18

operations, the clutch f grips the drum e, which is thereby caused to rotate with the driving shaft to which the clutch f is keyed, all the gears being locked together. The gears therefore have no relative motion, and the whole mechanism, including the propeller shaft, rotates at the speed of the driving shaft.

47. In Fig. 19 is shown another form of reversing gear. The internal construction consists of a gear keyed to the crank-shaft of the engine, surrounded by four or more pinion gears a running on stubs b, supported at one end by the cover c, which

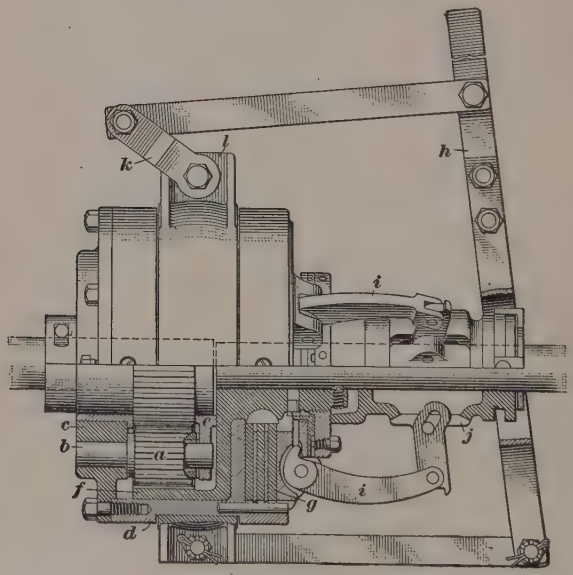

FIG. 19

is bolted to the external case d, and at the other end by a bronze pinion support c. The pinion gears a in turn mesh with the propeller gear f, which is an internal gear.

The forward drive is obtained by a multiple-disk clutch, the surfaces of which are formed by the rear end of the propeller gear f, a partition or web in the case d, and thin plates g, one half of which are keyed to the case d and the other half to the propeller gear. When the lever h is thrown forwards, the fingers i are expanded by a togglejoint j so that the friction

surfaces are clamped together, causing the propeller gear *f* and the case *d* to revolve as one piece. As the cover *c* is bolted to the case *d* and turns with it, the pinion gears *a* that are supported by the studs *b* in the cover and are in mesh with the propeller gear cannot revolve, and the whole device must turn as a solid coupling.

48. When the lever *h*, Fig. 19, is in the neutral position, which is its vertical position, the friction surfaces are released,

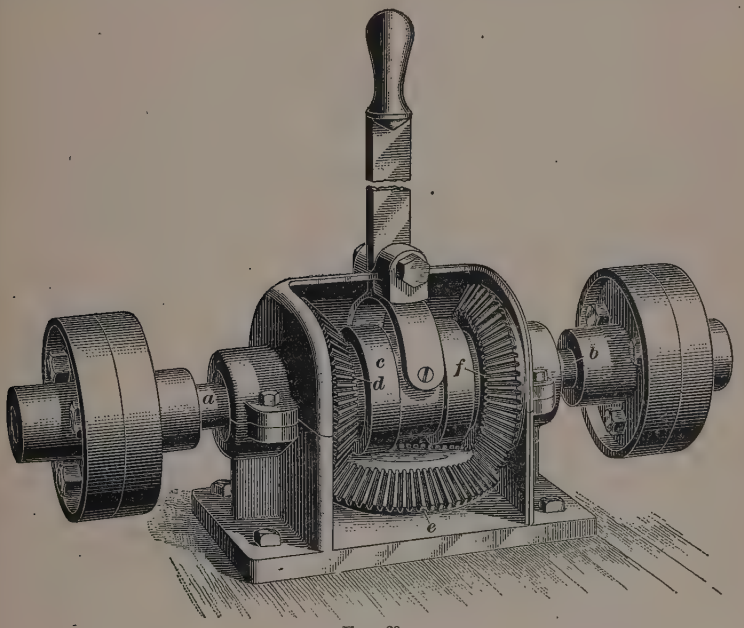

FIG. 20

the pinion gears *a* run idly, and only the case *d* revolves, so that no motion is transmitted to the propeller. The reverse motion is obtained by throwing the lever *h* backwards, or to the rear. The inclined lever *k* rides upon a double cam, which draws the brake band *l* together and clamps the outside case *d*, preventing it from revolving. The cover *c* that is bolted to *d* is also held stationary and the pinions *a* are caused to revolve in a direction opposite that in which the engine runs. The

gears *a* drive the propeller gear in the opposite direction from that in which the engine is running, and thus the reverse motion is obtained.

49. A somewhat different type of reversing gear is shown in Fig. 20. The driving shaft *a* is connected directly to the propeller shaft *b* by the clutch coupling *c* in the position it now occupies. In this position the gears *d, e,* and *f* do not transmit power, but the gear *f* turns idly on the propeller shaft. By throwing the clutch coupling to the other side, however, the shafts are disengaged and the clutch holds the gear *f* rigidly to the shaft *b,* and the direction of rotation is reversed.

50. In the type of reversing gear shown in Fig. 21 (*a*) and (*b*) the engine shaft *a* is keyed to the casing *b*. The stub shaft *c,* which is connected to the propeller shaft, is keyed to the friction cone *d*, the hub of which has a bearing in the casing *b*. The stub shaft can be moved endwise by moving the reversing lever *e,* which is pivoted at *f* and acts on the yoke *g,* held between the roller-bearing thrust collars *h*. Outside the stub shaft is a sleeve *i* that is keyed to the stationary bearing *j* by a feather key. Thus, it cannot rotate but can be moved endwise. Two pins *k* in the sleeve carry the pinions *l,* which may rotate on the pins but cannot swing around the central shaft. The pinions mesh with two gears *m* that are free to turn on the sleeve *i,* being held between collars *n* and *o*. The gears are extended to form cones *p* and *q* that may be engaged with the adjacent cone *d* and the cone on the inner surface of the casing *b*.

51. When the lever *e*, Fig. 21, is thrown over to the left, the friction cone *d* is moved to the left until its face engages the corresponding face of the casing *b,* as shown. The engine shaft then drives the stub shaft and the propeller shaft directly and in the same direction. To throw the gear into neutral position, the lever *e* is moved to the right until the cone *d* is disengaged from the casing. The engine shaft can then turn without driving the propeller. If the lever *e* is forced to the right, the inner face of the cone *d* engages the cone *p* and the whole sleeve is carried to the right until the cone *q* engages

the inner face of the cone on the casing *b*. Motion is then given by the casing to the cone *q* and its gear *m*. As the pins *k* carrying the pinions *l* are stationary, rotation of the right-hand gear *m* causes the left-hand gear *m* to turn in the opposite

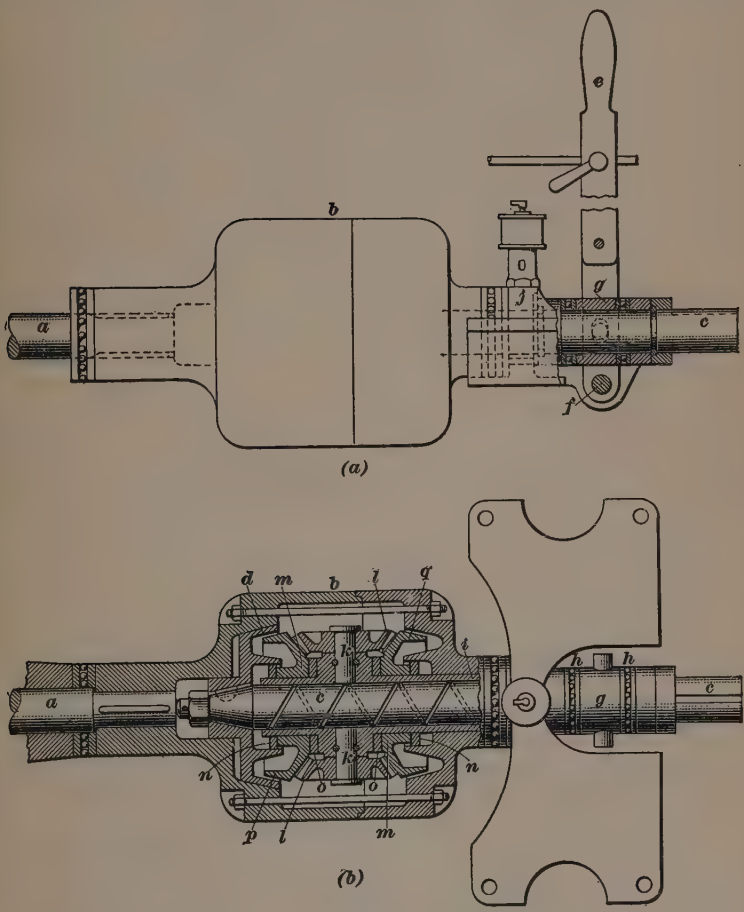

Fig. 21

direction and the same motion is communicated by the cone *p* to the cone *d*, which drives the stub shaft and the propeller shaft. Thus, the propeller is rotated in the opposite direction from that of the engine, and the motion of the boat is reversed.

SCREW PROPELLERS

52. The screw propeller is a very important part of the power equipment of a launch or motor boat. The rotary motion imparted to the crank-shaft by the gas engine inside the boat is given to the propeller outside the boat, and by its action on the water the boat is propelled forwards or backwards. Motor boats are seldom run backwards for any great distance, the backward motion being principally used when getting away from a wharf or dock, when stopping quickly, or when turning in a small space. The boat always moves more rapidly forwards than backwards, with the same expenditure of power. Propellers are made in various styles for different forms of service. They may have two, three, or four blades, which are equally spaced. The material used is generally bronze, because of its resistance to the corrosive action of salt water.

53. The form of propeller shown in Fig. 22 (*a*) is called a towing propeller, being adapted for use on heavy boats equipped with powerful engines, such a combination demanding a large blade area. The width of blade of this propeller is one-third of the diameter. A part of the surface at the back of the blade is made flat, to give effective power when the propeller is reversed. The form shown in (*b*) also presents a large surface of blade, but the outlines of the edges are sweeping curves of large radius and there are no parts of the blades that are flat. This propeller is designed particularly for high-speed motor boats, although it is also used on runabouts, cruisers, houseboats, and commercial craft. A weedless propeller is shown in (*c*). By making the leading edge *a* in the shape of a spiral receding in a direction opposite to that in which the propeller turns, and sloping the blades toward the rear, as at *b*, there is no tendency for the propeller to foul. Any grass or weeds encountered tend to slide along the leading edge toward the tip of the blade, where they are discharged, making a self-cleaning propeller. This type is useful on boats used in lakes, rivers, marshes, and other places where weeds

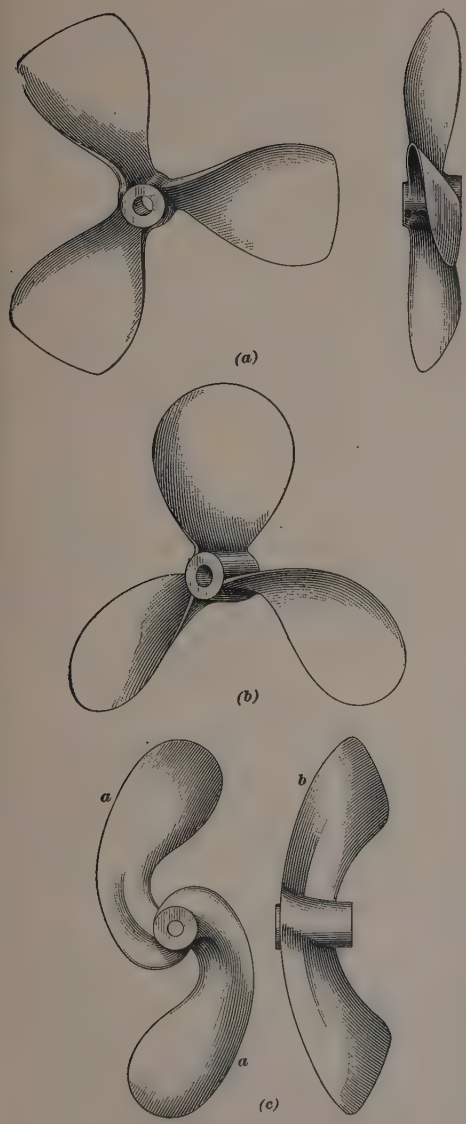

FIG. 22

may be encountered. The forms shown in Fig. 23 (*a*) and (*b*) are speed propellers, one with two blades and the other with three. Both are semi-weedless. The width of blade is about one-fourth the diameter of the propeller. These forms may be used on light boats, such as racing and pleasure boats.

54. As the propeller turns in the water, its motion is resisted by the water, and this resistance increases with the speed of the propeller; besides, when a propeller turns very rapidly, it churns the water without increasing the speed of the boat. The speed limit of propellers seems to be reached in practice at about 800 revolutions per minute; it is probable that, at speeds in excess of 800 revolutions per minute, even in very light boats, any increase in power at the engine is more than

counterbalanced and neutralized by propeller losses. In heavy, or working, boats, the loss of efficiency at high speed is very much greater than in light boats. In heavy head winds, working boats that make but little progress with the engine running at 350 revolutions per minute will do considerably better at 20 per cent. less speed.

55. The **pitch** of the propeller is the axial, or longitudinal, distance through which the propeller would force the boat, during one revolution, if there were no resistance to the boat's forward motion, and if the propeller had no lost motion due to its revolving in a non-solid substance. The amount these losses reduce the forward motion of a boat is called the **slip.** The pitch of a propeller is measured in the same way that the pitch of a screw is measured.

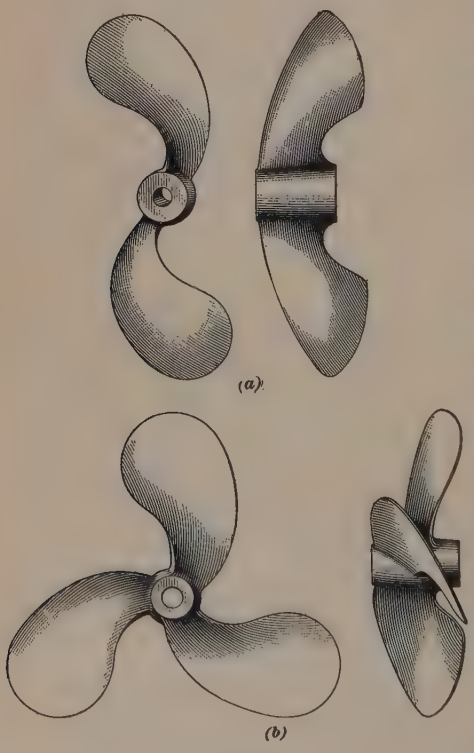

FIG. 23

56. In some cases it is found expedient to use **reversing** or **feathering blade propellers.** The blades may be feathered, or the angle at which the driving surface strikes the water may be so changed that the water is driven ahead instead of astern, without reversing the direction of rotation of the propeller shaft. Midway between the ahead and the astern position is a neutral zone in which an equal power

in both directions is exerted, with no effect on the boat in either direction. There is usually but one position of the blades that approximates true pitch, and on this account there is a considerable amount of power lost in their use, unless they are very carefully designed and specially built.

57. A sleeve sliding on the shaft and connected to the blades themselves, often within an enlarged hub, or attached to it and operated by means of a lever or hand wheel inside

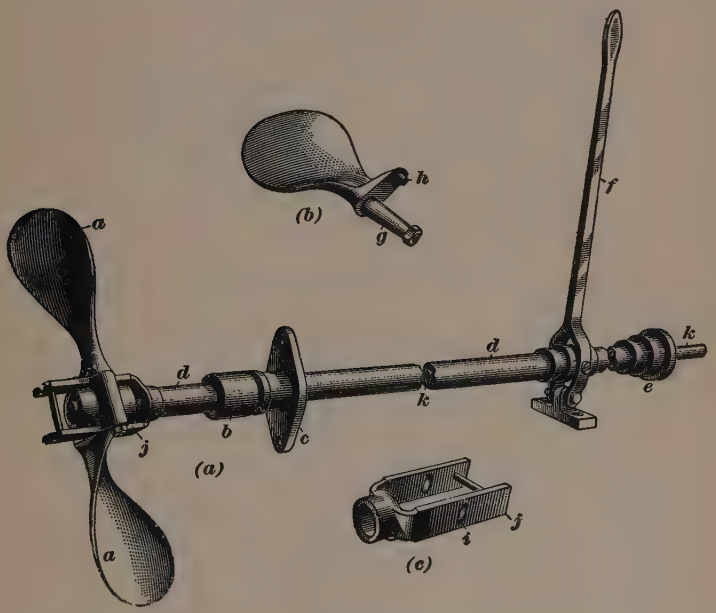

FIG. 24

the hull, is sometimes used to control the position of the blades. Such an arrangement is shown in Fig. 24 (*a*). The propeller blades are shown at *a*, the outside stuffingbox at *b*, the stern bearing at *c*, the sliding sleeve at *d*, the inside stuffingbox at *e*, and the reversing lever at *f*. One of the blades separate from the device is shown in (*b*), with the pivot *g* that fits into the hub and about which the blade turns. The pin *h* of this blade fits into the slot *i* in the fork *j*, views (*a*) and (*c*). The fork is attached to the sleeve *d*, and as the sleeve is moved forwards

or backwards the fork moves the pins so as to cause both blades to turn about their pivots. The propeller shaft is shown at *k*. The sliding sleeve revolves with the shaft, but is free to be moved along the shaft by the lever *f*.

MARINE-ENGINE OPERATION

STARTING AND STOPPING

58. Preparation for Starting.—When an engine is about to be started it is not safe to assume that all the adjustments are correct, just as they were when the engine left the shop, and only by careful examination can the operator be sure that the engine is ready for use. The following general rules may be applied whether the engine is of the two-cycle or the four-cycle type, either single cylinder or multicylinder:

First, determine which way the engine runs normally, whether right-handed or left-handed. When facing the flywheel and looking toward the stern of the boat, if the direction of rotation of the flywheel when the boat is going ahead is the same as that of the hands of a watch, the engine is a right-hand engine and requires a left-hand propeller wheel to drive the boat ahead. When the movement of the flywheel is contrary to the direction of movement of the watch hands, the engine is a left-hand engine and requires a right-hand propeller wheel in order to propel the boat ahead. When turning it over rotate the flywheel in its proper direction with the cocks open, or with the compression otherwise relieved.

59. Before attempting to start an engine, the control levers should be set so that the spark is retarded as much as possible and the throttle opened slightly. If the spark is not retarded, there may be a back kick that will injure the operator. If the engine is fitted with some form of clutch or reversing gear between the engine shaft and the propeller shaft, the lever of this gear should be set in the neutral position, so that when the engine starts it will have no external load. After the

engine has been brought up to speed and is working properly the clutch may be thrown into engagement.

60. Starting a Two-Cycle Engine.—If the engine is of the single-cylinder, two-cycle type, the easiest method of starting the engine is to prime the combustion chamber by injecting a few drops of gasoline into the priming cup with a squirt can, and turn on the gasoline supply in case a carbureter is used, priming it also by depressing the float; if, however, a vaporizer is used, set the needle valve at the point usually made on the dial when the engine is tested, swing the flywheel several times slowly back and forth through a space equal to about one-third the circumference, and then, taking hold of the starting pin, swing it up smartly against the compression in a direction opposite to its normal rotation, and then let go. If the engine does not start after trying this two or three times, close the valve in the gasoline supply, open the relief cock, and turn the engine over three or four times, and note whether or not explosions occur. The relief cocks should be open and the spark lever set so that ignition will occur either just after the center is passed or as near the end of the upward stroke as possible. By this test it can be determined whether or not there is trouble in the ignition system, and if there is, the trouble can be remedied.

61. A two-cycle engine may also be started by retarding the spark and turning the flywheel over against compression. By this method a good spark is obtained with the make-and-break system of ignition. When the engine has a very high compression it is often impossible to throw the wheel over. In this case the petcocks should be opened until the engine takes up its cycle of operations. Another way is to leave the petcocks on one cylinder closed until the engine is running.

Another way to start a two-cycle engine having a make-and-break system of ignition is to bring the wheel very hard up to compression in the opposite way in which it will revolve and snap the igniter trip. This produces a spark and the motor starts. If the motor is to be started in the reverse direction, bring the wheel up in the opposite direction and do the same.

62. When starting with a jump-spark system of ignition, the first thing to do after grasping the handle is to make sure that the spark is set late; then throw the wheel clear over. Anotner way is to bring the wheel hard up against compression in the opposite way from that in which the wheel will revolve and then throw in the switch, the switch having been left disconnected for the purpose. Still another method is to keep the switch connected and set the timer into a very advanced position; then bring the wheel up to hard compression and throw the timer into a late spark position, sending a shower of sparks through the mixture and starting the motor. This latter method should not be trifled with unless one is very familiar with the operation of a motor. However, all these methods should be tried, without the switch connected, until a person is familiar with them. It is a great help, when starting, to have the wheel marked in such a manner that it will show exactly when each piston is at the sparking point.

63. Reversing Two-Cycle Engines.—When there is no reverse gear, a jump-spark, two-cycle engine may be reversed without stopping the motor by bringing the timer to very late, so the motor will be running as slow as it can be kept going, then throwing the timer into a very advanced position. The engine will reverse because the advanced-spark position makes the spark occur when the piston is still rising, or on the upward stroke with engine going ahead. Because of the slowness and lack of momentum in the piston, the explosion, occurring before the piston has arrived at the center, is able to drive it back, and the motor is reversed. Were the spark created when the piston was in the same place at the time of starting, the engine would start in the reverse direction.

An advanced spark is frequently used, when the engine is driving ahead, for the purpose of obtaining the extra power created by the compression of the charge just as it has been fired, the momentum of the engine being depended on to carry the piston by the center.

64. Reversing on the switch is accomplished largely by becoming familiar with the sound of the motor. In time one

can become so accustomed to its sound that the time of the beginning of the upward stroke can be distinguished when the motor is running slowly. To execute the reversal, the circuit at the switch is opened, depriving the cylinder of the spark, and the motor immediately slows down. The trained ear of the operator catches the sound of the upward stroke and the switch is thrown into contact; an explosion takes place in the cylinder and instead of completing the upward stroke the piston is pushed back with force enough to make it take up the cycle reversed. On account of its construction, the two-cycle engine runs equally well both ways.

65. Starting a Four-Cycle Engine.—Before starting a four-cycle engine, see that the inlet and exhaust valves, and also the spark, are correctly timed; that the adjustments are correct; that all the valves seat properly, and that they are not rusted or stuck in their guides. A drop or two of kerosene oil should be used occasionally on the valve stems. Be sure that all the oil cups are filled; that all moving parts are properly lubricated, that the sea cock is open, and that there is nothing to prevent the free passage of water through the cylinder water-jackets and thence outboard. Look out for mooring ropes that may be caught by the propeller; a few accidents from this cause will usually teach caution as nothing else will. Make sure that the electric-ignition system is in good working order by testing it with the current on, if of the make-and-break type, or by the buzzing at the spark coil if jump-spark ignition is used. Open the relief cocks or push the relief cams into position, turn on the gasoline and see that it runs freely, and turn the engine over two or three times as fast as convenient.

66. To facilitate starting, it is sometimes better to put a little gasoline into each cylinder through the priming cocks. This operation is called *priming*. After two or three revolutions, the engine should start, when the relief cocks should be closed or the relief cams thrown out, and the speed of the engine regulated by the throttle, the proportions of the mixture being regulated by the auxiliary air valve or by the

needle in the gasoline valve, unless a compensating or other form of carbureter is used.

67. If the engine is directly connected to the propeller, there is nothing else to be done except to get the proportions of air and gasoline vapor as nearly right as possible; see that lubrication is constant, and that the circulating water discharges freely. If the engine has a reversing gear, there will be little need of throttling when changing from full speed ahead to a neutral position or full speed astern; but with a reversing gear and no governor, extreme care should be exercised when throwing in either gear or the engine may be stopped. The reversing gear absorbs some of the power of the engine, which is more liable to stop when attempting to go astern than ahead. It will be necessary, in case a governor is not used, to have some practice in order to be sure that the engine will not be stopped when throwing in the gears, and in order to be able to handle the throttle properly. With a governor, however, the manipulation of the engine is largely a question of properly proportioning the mixture of air and gasoline vapor and of proper adjustment.

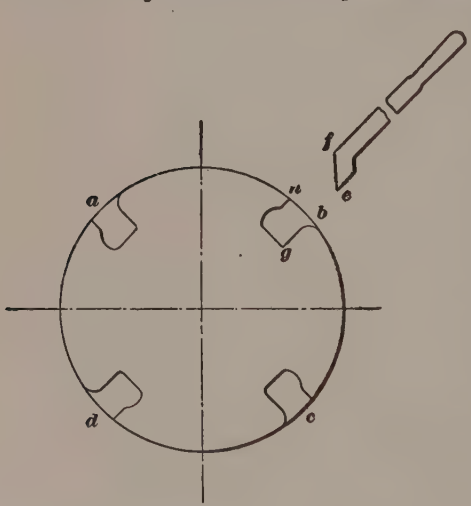

FIG. 25

68. Starting Devices.—The smaller sizes of gasoline and oil engines are started by simply grasping the rim of the flywheel and turning the engine over. In some cases, however, a starting pin is provided, which fits into a hole in the edge of the flywheel rim and serves as a handle. For somewhat larger engines a starting bar may be used. Fig. 25 shows

one method of using a starting bar. The flywheel for a single-, double-, or four-cylinder engine usually has four cored apertures, arranged 90° apart, with *a* and *b* usually 45° ahead and back of the upper center, respectively, and with *c* and *d* diametrically opposite *a* and *b*. There are two rows of these if the engine is designed to be run in both directions. In right-handed action, the lever has a toe *e* that comes against the side *g*, with the heel *f* against *h*. As soon as the engine starts, the lever is easily withdrawn; this is, perhaps, the simplest starting-bar system. On an engine with make-and-break ignition the use of a starting bar may invite injury. In pulling up on the bar and compressing the charge the cam pushes the snap rod up and if the operator allows the engine to turn backwards the make-and-break device is apt to cause a spark and produce a back kick.

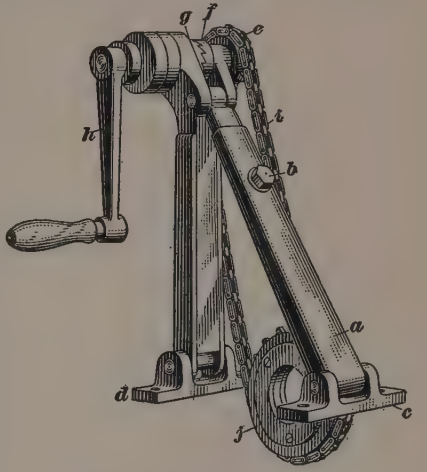

FIG. 26

69. Some makes of engines are fitted with crank starters geared to the crank-shaft by chain and sprocket wheels. One form of such starter is shown in Fig. 26. The frame *a*, which is adjustable by means of a clamp bolt *b* in each leg, is pinned to two brackets *c* and *d* that are bolted to the bed of the engine on opposite sides of the crank-shaft. At its upper end the frame carries a housing that forms a bearing for a short shaft to which are keyed the sprocket pinion *e* and one half *f* of a toothed clutch. The other half *g* of the clutch is fastened to a shaft that carries the crank *h*. A chain *i* connects the pinion *e* with a sprocket wheel *j* on the crank-shaft of the engine. When the parts *f* and *g* are engaged and the crank *h* is turned, the engine shaft is rotated. But when the engine has been started and is running, an automati-

cally operated pawl in the sprocket *j* disengages it from the crank-shaft and the chain ceases to run.

70. Stopping a Gasoline Engine.—When the engine is to be stopped, the switch should be thrown out and the oil cups shut off. When using reversing gears, it is always better to stop in the neutral position, going neither ahead nor astern, for it is usually much easier to release a clutch when the engine is running than after it has been stopped. The gasoline-supply valve, which should always be placed in the supply pipe directly back of the vaporizer or carbureter, should then be closed.

71. Among several reasons for adopting this method of procedure when stopping an engine the following may be mentioned: If the engine is stopped by entirely closing the throttle, its closed position may not be noticed when attempting to start, and with the throttle closed the cylinder will be filled with a charge of burned gas instead of a fresh charge of explosive mixture; the engine should not be stopped with the switch on and the make-and-break electrodes in contact, as the batteries will thus soon be exhausted.

72. Tracing the Cause of Failure to Start.—In a general way, when a motor does not start the first thing to do is to try the spark. This is done by turning the flywheel until the make-and-break or the timer contacts touch. Then, if the buzz of the vibrator is not heard the fault is in the ignition system. If the vibrator sounds with the usual vigor, the gasoline supply should be suspected. The needle valve of the carbureter and the valve at the tank should first be examined; if these are right a priming charge should be put into the cylinders either through the priming cups or squirted through the open petcocks from a small oil can with a point fine enough to project past the turning cock, that the charge may surely go into the cylinder. If the electric circuit is all right the motor will almost surely start after a moment and run either steadily or until the injected gasoline is used up, for this method will often bring a poor mixture into regular explosions by the heating of the cylinders. It does not all burn with the first explosion. Should the motor stop when the injected gasoline

is used up, the shortage of fuel is a surety and the tanks should be examined.

73. Causes of Refusal to Start.—The most frequent causes for a motor not starting are an open switch and a closed valve in the gasoline line either at the tank or at the carbureter.

Sometimes a new engine piston is so tightly fitted that it seems impossible to get the machine going after it has lain idle long enough to let the cylinders cool off. The condition may best be expressed by the term *frozen*. The remedy is to have the spark and all in first-class order and then to squirt into the cylinders a good spoonful of oil and work the piston up and down a number of times. Then, if the engine is primed with gasoline it will almost always start.

Many times engines have been started after long struggles by simply injecting a few squirts of oil into the cylinders. Rocking the wheel two or three times with half turns will have the effect of priming.

CARE AND REPAIR OF PARTS

74. Care of Pumps.—The water pumps located in the cooling system need attention at times. The packing will get worn and the suction diminish because of air getting through it. In such cases, loosen the packing nut and take out the old packing. Replace with some regularly made packing, or, what is easier, some lamp wicking of the soft stringy kind smeared with soft graphite.

75. Troubles in Water Circulation.—The lack of water in the pipes is manifested by the smell, by a smoky vapor rising from the water-jackets or the exhaust pipes, or by a difference in the sound coming from the motor. Generally, a quick remedy is to rap the valves on either side of the pump, as the main trouble is caused by particles lodging in the valves and the rapping will in most cases jar them free. If this is ineffective, the trouble may be with the screen at the inlet on the bottom of the boat. In this case, reach over the side and

scrape the screen, using a long stick. If out of reach with a stick, back the boat and throw the obstruction off.

76. Laying Up Engine.—As the cold weather comes on care should be taken that after returning from a run the water is drawn off from the entire circulation. This is necessary in order to prevent freezing. When housing the boat for the winter, disconnect all pipes in which water can lodge and blow out the water. Empty the carbureter and tanks. Put all of the electrical equipment in a dry place, where there is some warmth if possible; the coils will be better for it in the spring. Take off all fittings that are movable; if prowlers can get near the boat, even the propeller will not be safe. Unscrew the cylinder head and give the inside of the cylinder a good cleaning, removing all carbon and gummed oil, particularly back of the piston rings. Open the crank-case and clean and flush it. Put on the cylinder heads, fill the cylinders with oil; the oil will not evaporate, consequently will not gum, and the finish on the cylinder walls will be preserved. Any parts of the engine that were painted to preserve it from rust should be touched up; the other parts should be cleaned of all dirt and smeared with a thin coating of grease. Throw a canvas over the whole and fasten it down snugly. Rub up the tools and smear them with grease.

77. Cleaning the motor is generally the least congenial part of power boating. It can be made more agreeable, however, by using a paint brush, with a long handle, that has been dipped in kerosene. This method enables one to reach all sorts of places otherwise inaccessible and is quick and does the work.

78. Clutch Troubles.—The principal fault with clutches is their tendency to slip. In many cases this comes from oil getting into the disks or the band, supposing that the clutches are of the dry type. In other cases the slip is from wear or because the power of the engine is greater than the clutch was designed for. The action of the clutch depends on the friction between the clutch surfaces. Any failure of the clutch to

carry the load is, therefore, caused by either grease on the surfaces or insufficient pressure. A careful examination will generally reveal the cause and suggest the remedy.

In cases of emergency, the thing to do is to release the clutch and place between the bands or the disks, nails, small tools, or anything that is strong enough not to be torn to pieces when the engine is started. If they can be so placed that they will stay in position until the engine is started, and will hold their place during the moment of becoming engaged, the engine can be started and the clutch thrown in. The object of inserting the nails or small tools is to take up the wear and force the clutch to become fully engaged before the entire compressive force is thrown upon it when the lever is pushed in.

The probability is that nothing can be made to stay between the clutch surfaces when the clutch is thrown in after the engine is started; therefore, the pieces must be inserted and the clutch jammed up solid before the engine is started. There is then no chance to reverse the clutch. Some boats carry a length of shafting made to insert in the place occupied by the clutch. If the clutch goes wrong it is taken out and the short length of shaft is inserted in its place.

79. If the engine is too powerful to be started with a fixed shaft in the ordinary way, some means of leverage should be applied to the crank to get the pistons in two of the cylinders up to and a trifle beyond compression, then the switch thrown in and a spark produced. If this cannot be done and a short tow can be secured from a passing vessel the engine will be easily started during the towing process, as the towing will not only relieve the resistance but will perhaps start the engine by the pressure on the propeller without assistance from the operator.

80. If there is no emergency, it is better not to place anything in the clutch as doing so is apt to damage the clutch. It is better to secure a tow and then send the clutch to the repair shop. A clutch slipping because of oil can be washed with gasoline, or dirt or sand may be inserted, although the latter is not good practice as it might destroy the clutch.

81. Leaky Stuffingbox.—Leaks in the stuffingbox are frequent. When packing them one should use the square packing that is provided for the purpose by the supply houses, but before putting in place the packing should have a liberal quantity of graphite spread over it. The packing nut should then be screwed up moderately tight. Before tightening the setnut, or locknut, the petcocks on the cylinders must be opened and the wheel thrown over, being sure that there is no spark. If the wheel turns too easily, the stuffingbox can be set up a trifle tighter. If the wheel turns hard, the stuffingbox should be loosened until the wheel feels right. The stuffingbox should be set a little stiff on account of subsequent loosening.

82. When on a trip it is sometimes necessary to renew the packing. In such cases, when tightening up care must be taken not to strip the threads or the regular packing will not stay in. Should the threads be stripped, the box may be packed by smearing some shredded marlin or cotton waste with grease or graphite and pressing small threads of this packing between the shaft and the box with the point of a knife. In order to do this the stern of the boat should be run up on the beach, but the part of the stuffingbox that was uninjured may be packed with the regular packing. With an inside stuffingbox it is not necessary to haul the stern of the boat up on the beach to get at it. After setting up on the stuffingbox nut the amount of resistance to cranking will tell if the stuffingbox has been set up too tight.

83. Sand in Stuffingbox.—It is bad for the engine and for the shaft to send the boat through mud or sand and particularly to back it through, as is the habit with some when a spot that is just too shoal for the boat is encountered. The backing of the boat through sand is in reality dredging a channel with the propeller. During the process sand is thrown into the water circulation and works into the stuffingbox, much to the detriment of both. A little sand in the stuffingbox will cut the shaft so quickly that the propeller will be wobbling

in a short time. The result is such vibration and strain that the shaft will need to be replaced or reversed.

84. Knocking or Pounding.—Aside from the knocks produced by loose bearings or preignition, a loose flywheel will produce a sound as if the bottom of the boat were being pounded out, but it is not so serious as the sounds indicate. However, before going out for another run it should be attended to. Generally a resetting of the key is all that is needed and the flywheel may be set up tight by the operator.

The pump eccentric may cause a knock for want of grease. The pump may knock because of the packing being too tight; or for want of a few drops of oil being poured into the packing.

The loss of a ball or two in the thrust bearing may produce a knock. If missing, the balls should be restored at once.

85. A shaft out of true will make a pound. It may be learned if this is the cause by watching the shaft as it revolves. When out of true the shaft must be taken out and straightened. A bend in the shaft can be discovered by stretching a length of strong linen or silk thread along the shaft, holding the ends taut over the ends of the shaft. The shaft may be straightened by laying it on a long straight stick of timber with the bent side of the shaft arching upwards and hammering it with a sledge, holding a block of wood between the shaft and the hammer. A block of wood about 3 inches by 4 inches will answer. By repeatedly testing the shaft with the thread it will be found that a few minutes will suffice to do work as well as can be done in a shop.

It may be well now to examine the ends of the shaft and see whether it has become scored at the stuffingbox. If it has, the shaft should be turned end for end, if possible, or renewed.

86. During a run one or more of the propeller blades may have been bent by coming in contact with a log or other obstruction. The blade, being of soft metal, will bend easily. The result is apt to be more or less of a pound and a pronounced vibration. Nothing can be done but get into the nearest harbor

as soon as possible and have the propeller taken off. The blade can then be bent back to place, or nearly so, by laying it on a heavy block of wood and straightening it with a hammer, interposing another piece of wood between the hammer and the blade.

The bolting to the base of the motor will sometimes work loose and cause a pound. This will also cause lack of compression in the base.

Loosening of the engine-bed bolts will create either a pound or excessive vibration. If the bolt holes or lagscrew holes have worked larger it is better to put in new bed pieces.

Back pressure, from the outboard end of the exhaust being suddenly depressed as in wave motion or by having too much weight on the stern, will cause pounding. Too much water lying in the muffler will cause a pound each time the gas forces itself through the water.

87. Propeller Racing.—In a sharp head sea as the boat lifts over the crest of a wave and begins the downward plunge the propeller will come out of the water and being relieved of the resistance the engine will race at terrific speed and is consequently damaged. If the sea is of such a nature that this is liable to happen frequently, the course should be changed so as to send the boat over the crests in a diagonal direction. In doing that, the strain on the engine, also the boat, is lessened and the rearing and subsequent fall and pound are very much modified. After the boat has been on the new course for a while, the proper course to be run can be maintained by shifting the course so that the seas will be on the other bow. In this way the boat beats to windward the same as is done by a sail boat.

88. Crank-Case Requirements.—The crank-case must of necessity be air-tight in a two-cycle engine, for in it the fresh charge of mixture is to be compressed. To be efficient it must also be free from excess oil, and should be entirely free from sediment. Sediment in the crank-case will be picked up by the lower end of the connecting-rod in its revolutions and carried by the splashing to the sides of the piston, and by the

piston to the walls of the cylinder. Smoke issuing from the crank-case indicates that the crank-case is not air-tight and that the piston is leaking exploded gas past its rings from the cylinder.

89. Explosions in the crank-case of a two-cycle engine are due to a lack of fuel in the mixture and are caused in the same manner as back firing in the inlet pipe. All crank-cases should have a drainage cock so that they can be cleaned frequently. Where the chamber is bolted together horizontally through the center, the joint may be made tight by coating both sides of the gasket with graphite. The oil in the crank-case should rise high enough to be ½ inch deep on the lower ends of the brasses on the connecting-rod.

90. Cleaning the Crank-Case.—In many cases, the crank-case of a two-cycle engine will become so filled with oil, gasoline, and dirt that a proper mixture is impossible. It should first be drained by means of a drainage cock, or a plug at the bottom, which may be opened or taken out. It should then be flushed out well with kerosene to clean it of dirt and grit. When the cleaning operation is over some oil should be put into the case so that the connecting-rod can splash it up and oil the brasses, otherwise the brasses may be burned out. A handy way to take the excess oil out of the crank-case is by means of long-stemmed squirt guns, or syringes.

91. Loss of Base Compression.—In two-cycle motors, there may be loss of compression in the crank-case where the shaft enters and leaves the base. The check-valve in the base of two-port, two-cycle motors may not seat well because of dirt, carbon from base explosions, or from a weak spring, thus causing loss of compression. There should be from 2 to 5 pounds compression in the crank-case according to the design of the engine. If there is not, the mixture, which is drawn into the base and compressed, will not be forced into the cylinder with enough vigor to expel all the burned gases. This will leave the next charge so weak that it will explode weakly or not explode at all, or, it may explode so slowly that the fire will

linger until the next charge is entering the cylinder and, by firing it, cause a back fire into the crank-case or the carbureter.

The loss of compression may be due to leaky gaskets of the crank-case, which may be worn or may have been frayed when the parts were bolted into place.